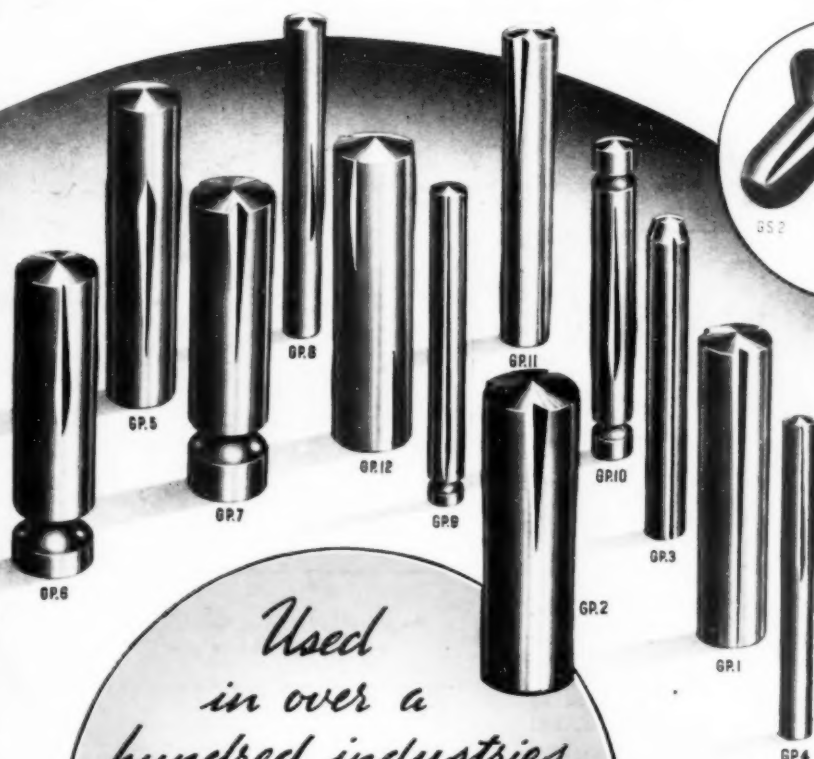


# METALLURGIA

THE BRITISH JOURNAL OF METALS

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TAPER PINS, SCREWED PINS  
AND MANY OTHER TYPES OF  
FASTENING, WITH SAFETY,  
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NO REAMERING, NO TAPPING,  
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SIMPLY DRILL A PLAIN PARALLEL  
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MADE IN STEEL, BRASS, COPPER,  
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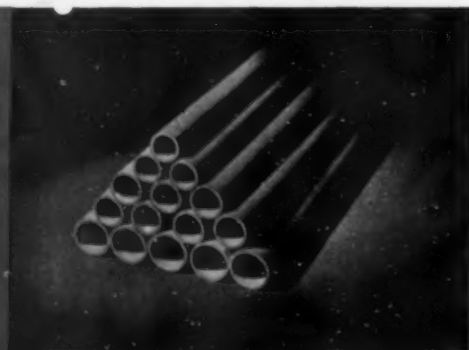
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COMBUSTION  
TUBES**

These special refractory tubes are a new development for temperatures above the limit of VITREOSIL (1050° C.) and below the range of the more refractory tubes of FUSED ALUMINA, MAGNESIA, etc.

MULLITE COMBUSTION TUBES can safely be used at temperatures up to 1500° C. under normal conditions, and practical tests in large steelworks' routine laboratories have proved them to be eminently suitable for use in electrically heated furnaces for determination of the carbon and sulphur contents in steel at 1200-1300° C.

Resistant to thermal shock and attack by iron oxide, and relatively insoluble in most slags and glasses even where the lime and alkali contents are appreciable, MULLITE COMBUSTION TUBES are superior to porcelain in all respects.

Write for descriptive leaflet giving prices.



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UP TO 1500°C.**

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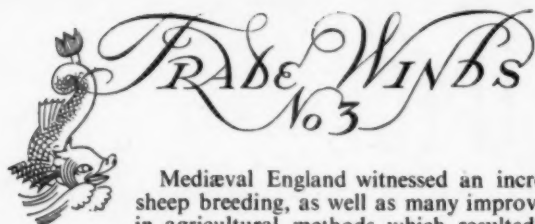
London Office:

12-14, Old Pye Street, Westminster S.W.1





Painting by Lance Cattermole, R.O.I.



Medieval England witnessed an increase in sheep breeding, as well as many improvements in agricultural methods which resulted in an impetus to the export of wool and corn. At first little ships averaging 30 'tuns' carried the cargoes from our inland ports to those of the nearby Continent.

In opening out this seaborne trade the hazards and physical dangers to be surmounted were formidable. The smallness of the craft, lacking any navigating instruments, added to their peril. The masters had to face unknown ocean currents, tidal races, storms, fogs, unlit rocky headlands and uncharted islands, yet despite such obstacles and the absence of set courses, trade gradually developed along the coasts of Northern Europe.

Marts of English wool were established at Bruges, Antwerp and Calais and became so important that the merchants were granted exclusive rights by Royal Authority to buy and sell in certain specified towns known as

## THE VENT OF CLOTH

"Staples." The trade of London, Southampton and Bristol was built up in this fashion. Wool and grain ships ploughing across the Channel brought back French wines and other luxuries.

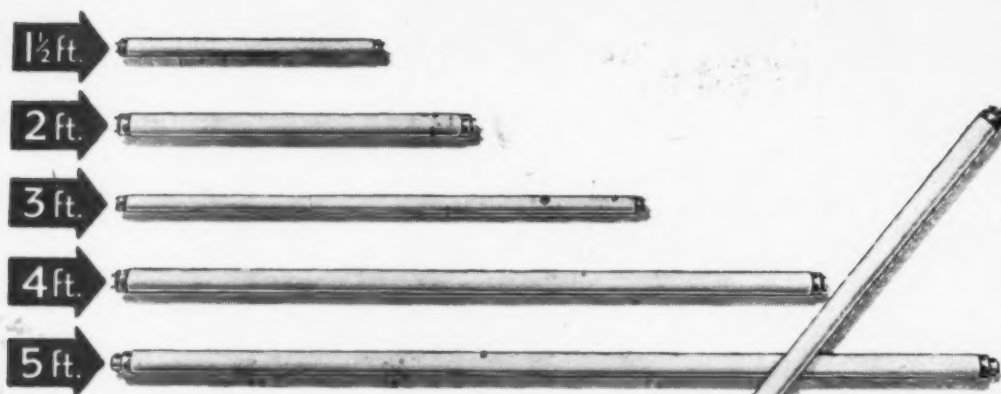
Before Elizabeth came to the throne the energy and initiative of the merchants had made them both rich and politically powerful, yet the export of wool waned and suffered extinction in the loss of Calais, known for generations as "The Staple."

The trade with the Low Countries also ceased because of political, religious and economic differences between Elizabeth and the Spanish Governor of these territories. It was a severe blow to the country, but craftsmen were fast learning the art of weaving wool, and at the same time our shipbuilders and sailors were improving the maritime arts. The inspiration of the Queen, the spirit of the City, allied to the enterprise of free men, created vast new markets further afield than the old Continental ports, and England entered upon a new trade for the Vent of Cloth.



## THE UNITED STEEL COMPANIES LIMITED, SHEFFIELD

STEEL PEECH & TOZER, SHEFFIELD • SAMUEL FOX & CO. LTD., SHEFFIELD • APPLEBY-FRODINGHAM STEEL COMPANY, SCUNTHORPE, Lincs.  
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*and now -* **Osram**

**8 ft.**

## **FLUORESCENT LAMPS**

With suitable *S&C* fittings and gear  
**NOW AVAILABLE**

**8 ft. 1 1/2 inch diam. 125 watt in "NATURAL" COLOUR**

This lamp, with suitable gear, can also be operated at 75 watts

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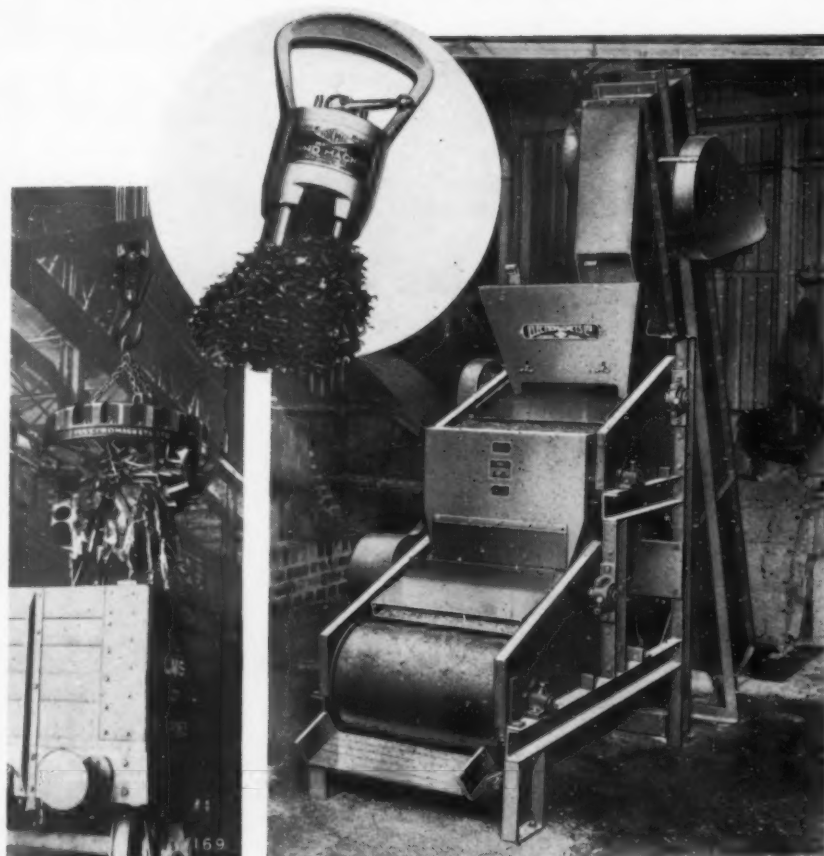
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H (for Hiduminium) was born to be a giant killer—a versatile lightweight with the strength of rivals three times his weight. For twenty-one years he's been piling up points in his fight against the power of g (for Gravity). Hiduminium provides a combination of strength and lightness. Hiduminium reduces stress, running costs and handling charges. Hiduminium is easily formed, resists corrosion, is non-toxic, has chemical stability and many other advantages which are available to manufacturers who choose to . . .

. . . make light work of it with **Hiduminium**

HIGH DUTY ALLOYS LTD., SLOUGH, BUCKS, INGOTS, BILLETS, FORGINGS, CASTINGS & EXTRUSIONS IN 'HIDUMINIUM' & 'MAGNUMINIUM' ALUMINIUM & MAGNESIUM ALLOYS  
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## Handling and separating Iron by Magnet

For every problem of handling Iron—or of separating loose iron from liquids or solids

there is an answer in 'standard' equipment—or we will find it by special design.

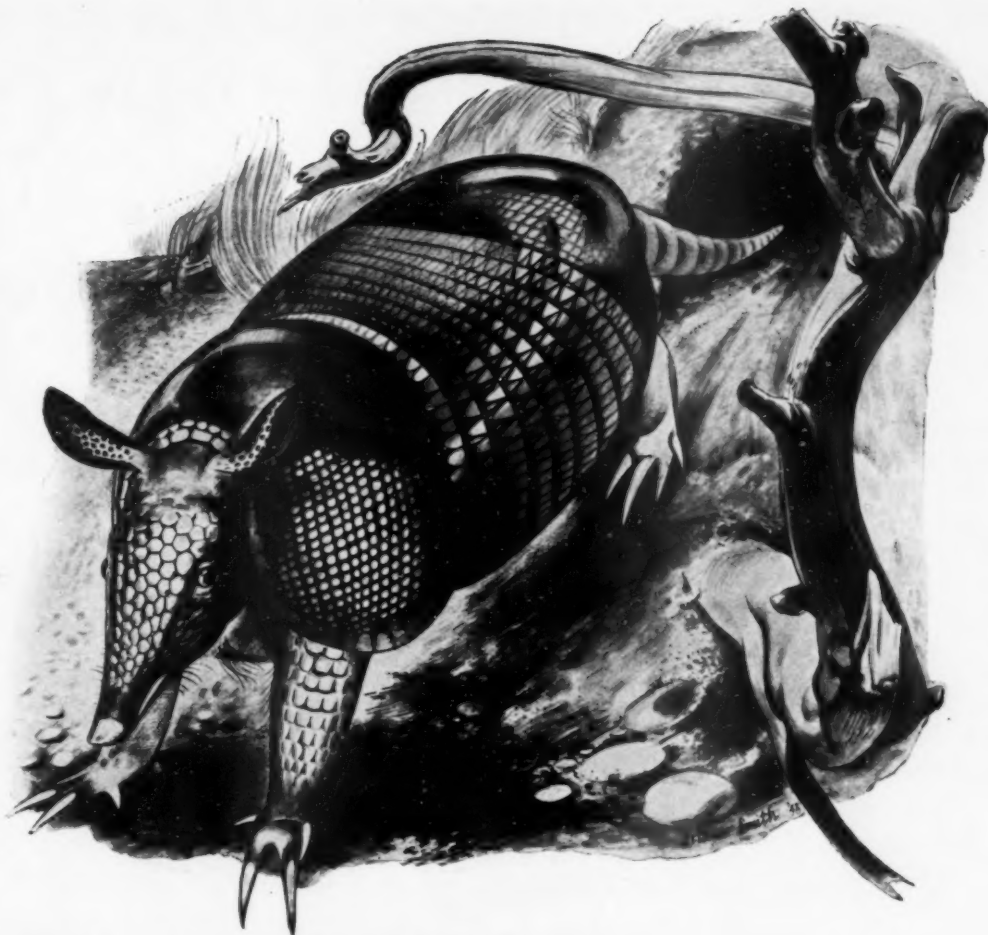
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. . . but casehardened parts must be free from scale.

For surface hardening or applying case depths up to 0.02 in., use:—

## 'CASSEL' CYANIDE SALT BATHS

For details of 'Cassel' Heat-treatment Salts and  
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C.C.136



## This question of creep

Good creep strength (resistance to failure under sustained loads at elevated temperatures) is essential in steel for jobs where heat is unavoidable.

Molybdenum steels are noted for their good creep strength. Therefore they are ideal for parts in superchargers, gas turbines and steam turbines where close clearances must be held in spite of heavy loads at high temperatures.

Your supplier can tell you about the steels, and a letter will bring our technical book that describes them in detail.

CLIMAX MOLYBDENUM COMPANY  
OF EUROPE LIMITED  
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# MOLY

WHEN THE PROBLEM IS  
TEMPERATURE CONTROL  
THE ANSWER IS . . . .

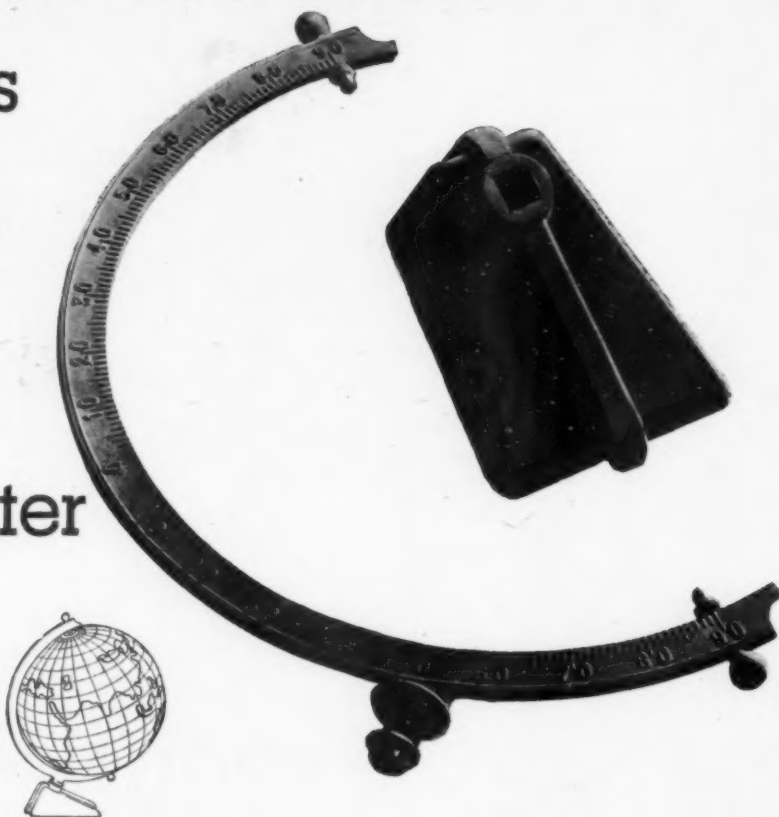
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★ Ask us for appropriate literature—  
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ELECTRON ALUMINUM SUPERHEATED  
Mag. X 300

TAS/SC. 202

Excuse our enthusiasm  
but to us  
these  
parts  
are greater  
than  
this whole



ZINC CAN HELP in the form room as well as in the factory. For instance it contributes several essential parts to this globe\* which is being produced in very large quantities for the home and export markets.

#### Why the parts are zinc alloy die cast

The pivots on which the globe revolves are die cast in zinc alloy (and the world would be a better place if its affairs went round as smoothly as this globe does!). For the thin meridian, too, zinc alloy pressure die casting was the ideal production process, firstly because zinc alloy is specially suitable for casting very thin sections, and secondly because the meridian can be made with the raised degrees of latitude cast on it. Finally, the base is a zinc alloy die casting. The globe is made in 13½ in. diameter (with other sizes to follow)

\* Photograph reproduced by courtesy of George Philip & Son, Ltd.

and the die cast parts are given an attractive gilt finish.

#### Other educational uses

Zinc alloy die casting is also used for the minutely accurate quantity production of microscope frames, projector parts, lantern parts, epidiascope parts, film viewers and drawing instruments.

#### Some facts about zinc alloy die casting

Speed of production is an outstanding feature of the die casting process — the shortest distance between raw material and finished product. Zinc alloys are the most widely used of all metals for die casting because they yield castings with the following qualities:

**STRENGTH:** Good mechanical properties for stressed components.

**ACCURACY:** Castings can be made practically to finished dimensions and need little or no machining.

**STABILITY:** Close tolerances are maintained throughout the life of the casting.

These are the properties which accounted for the widespread wartime use of zinc alloy die casting in the quantity production of such things as fuses, gun sights, periscopes and tank carburettors.

#### British Standard 1004

Alloys conforming to B.S.1004 should be specified for all applications where strength, accuracy and stability are essential.

**ZADCA**

ZINC ALLOY DIE CASTERS ASSOCIATION  
LINCOLN HOUSE, TURL ST., OXFORD  
TELEPHONE: OXFORD 48088

ZINC ALLOY DIE CASTINGS PLAY AN IMPORTANT  
PART IN THE EXPORT MARKET

Enquiries about the uses of zinc alloy die casting are welcome. Publications and a list of Members will be sent on request.



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## ALLOY & SPECIAL CARBON STEELS

Manufacturers of  
BARS • SHEETS • PLATES • WIRE RODS

Established 1873

TRADE MARKS



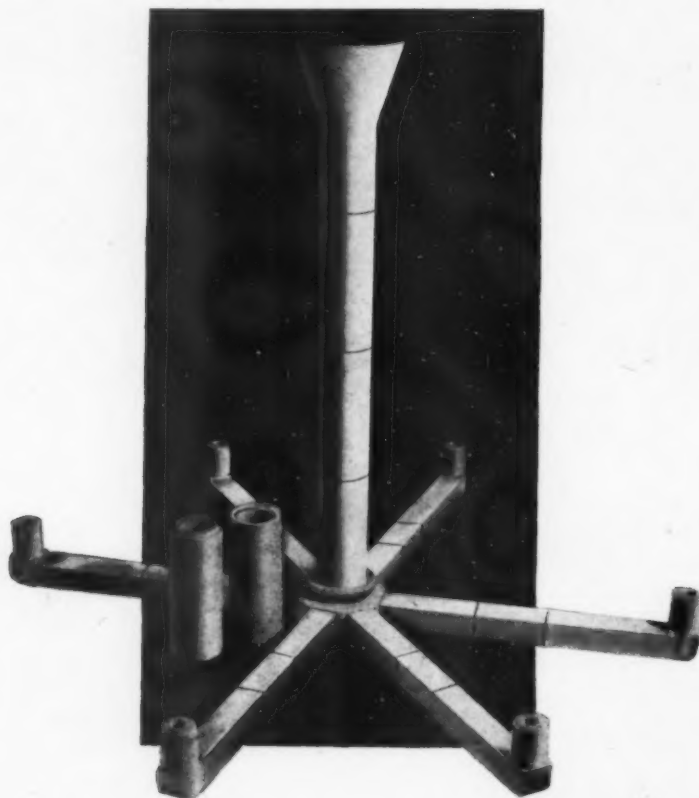
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# MARSHALL'S



## R E F R A C T O R I E S

The illustration shows a typical 6-way uphill casting assembly as used for casting nests of large ingots in a modern Steel Works, shorn of its outer casings.

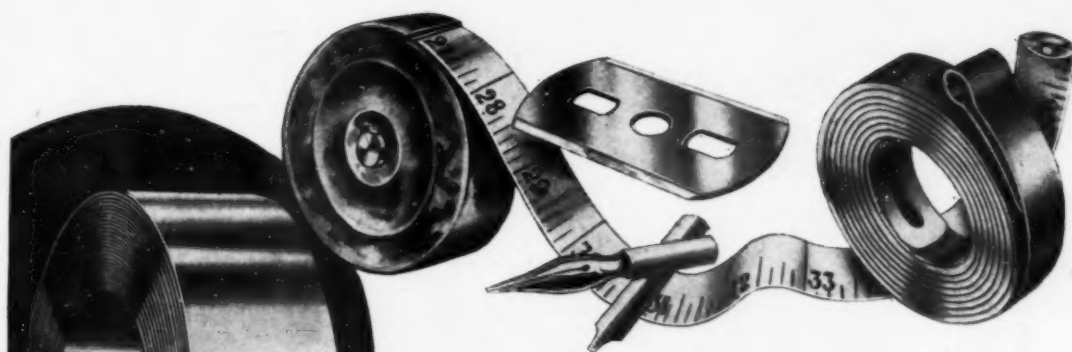
The excellent jointing, which is a feature of our bricks, can be seen at all points, and modern methods of technical control are used in production to assure the maintenance of this high standard.

**THOMAS MARSHALL & CO. (LOXLEY) LTD.**

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### HIGH CARBON .004" TO .020" THICK

Our strip rolling plant has been laid down specially for producing bright cold rolled strip steel only in these thin sizes and high carbons. We do not manufacture soft strip of the deep drawing quality.

## COLD ROLLED BRIGHT STEEL STRIP

TOOL STEELS.  
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# SANDERSONS

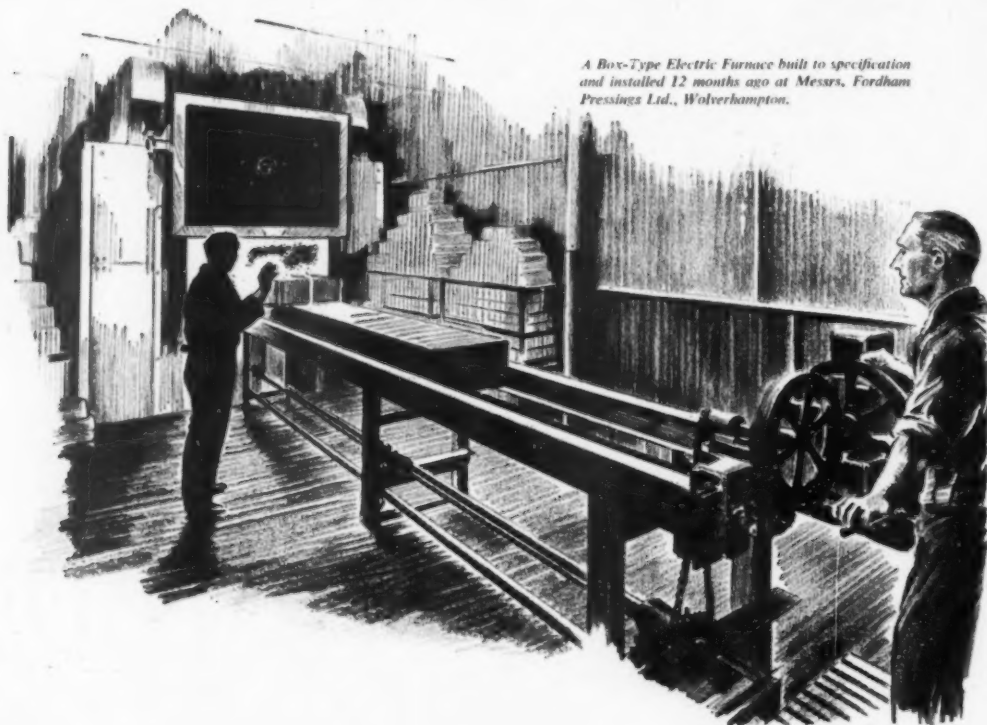
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ATTERCLIFFE WORKS, SHEFFIELD

ALLOY STEELS  
CIRCULAR  
CUTTERS.  
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# Electric Furnaces in Action

No. 1



*A Box-Type Electric Furnace built to specification and installed 12 months ago at Messrs. Fordham Pressings Ltd., Wolverhampton.*

Mr. C. Parker of Messrs. Fordham Pressings Ltd., says:

"Where vitreous enamelling is concerned, the highest standards of quality and production are attained only when conditions of atmosphere and materials used can be calculated and controlled to the last degree of accuracy. In these respects, we find this Box-Type Furnace, built by G.W.B. to our own specification, remarkably efficient. During the 12 months it has been installed it has done its job perfectly, with very little adjustment or repair-work."



Thus do G.W.B. Furnaces—whether of standard design or designed specifically for our clients' needs—contribute to the quality of their products.

*Illustrated below is a typical G.W.B. Box-Type Electric Furnace of Standard design.*

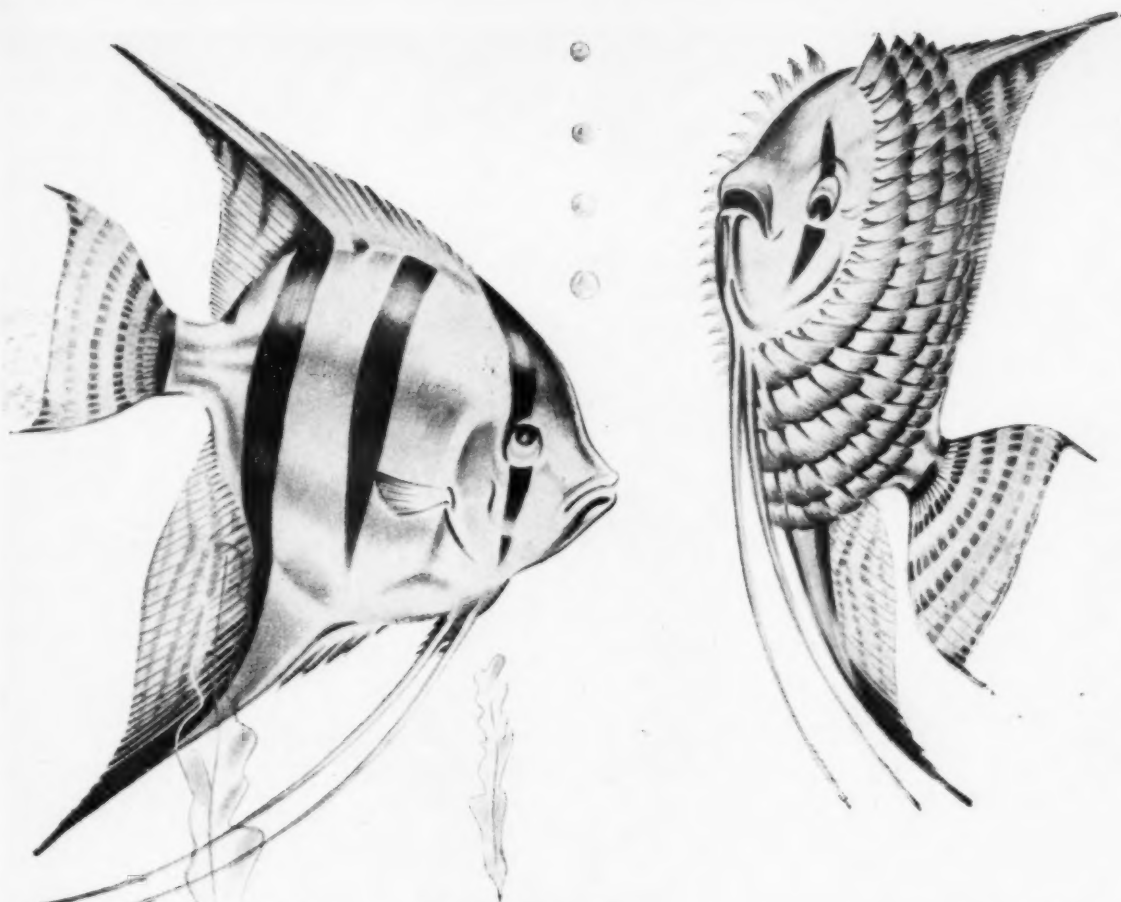


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DIBDALE WORKS, DUDLEY, WORCS.

Proprietors: GIBBONS BROS. LTD. and WILD-BARFIELD ELECTRIC FURNACES LTD.





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This is not a nightmare—not even a buyer's nightmare. The Renfrew organization is specifically designed to iron-out buyers' problems—the new design, the modification, the job that is always wanted immediately. We welcome small orders; they represent a considerable volume of the output of our mechanised production lines. Renfrew handles an urgent small order as promptly as a large one, and at an attractive price. Become another Renfrew enthusiast by sending us your next rush order.

NOT TOO BIG • NOT TOO

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SMALL NEEDS



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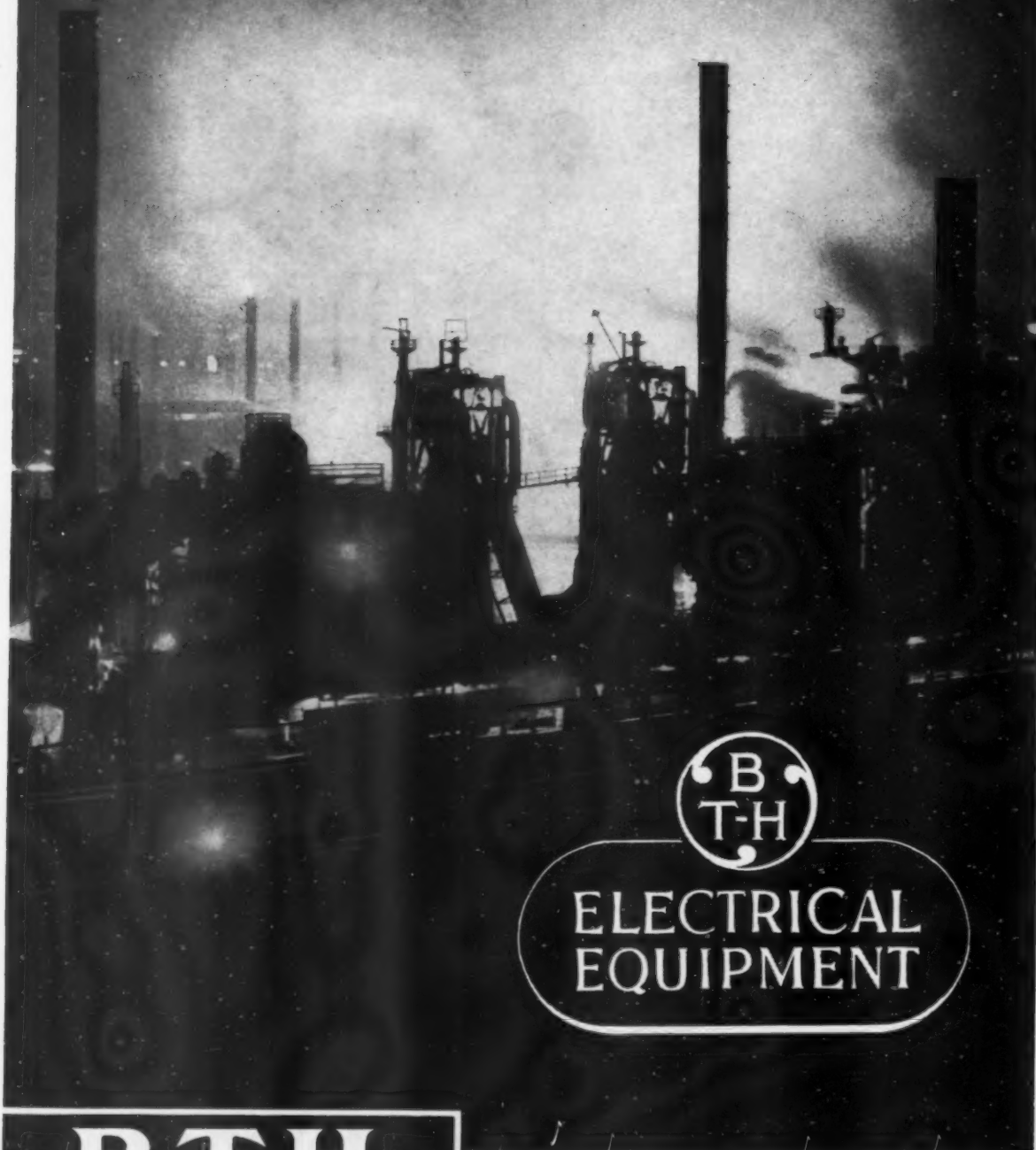
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ELECTRICAL  
EQUIPMENT

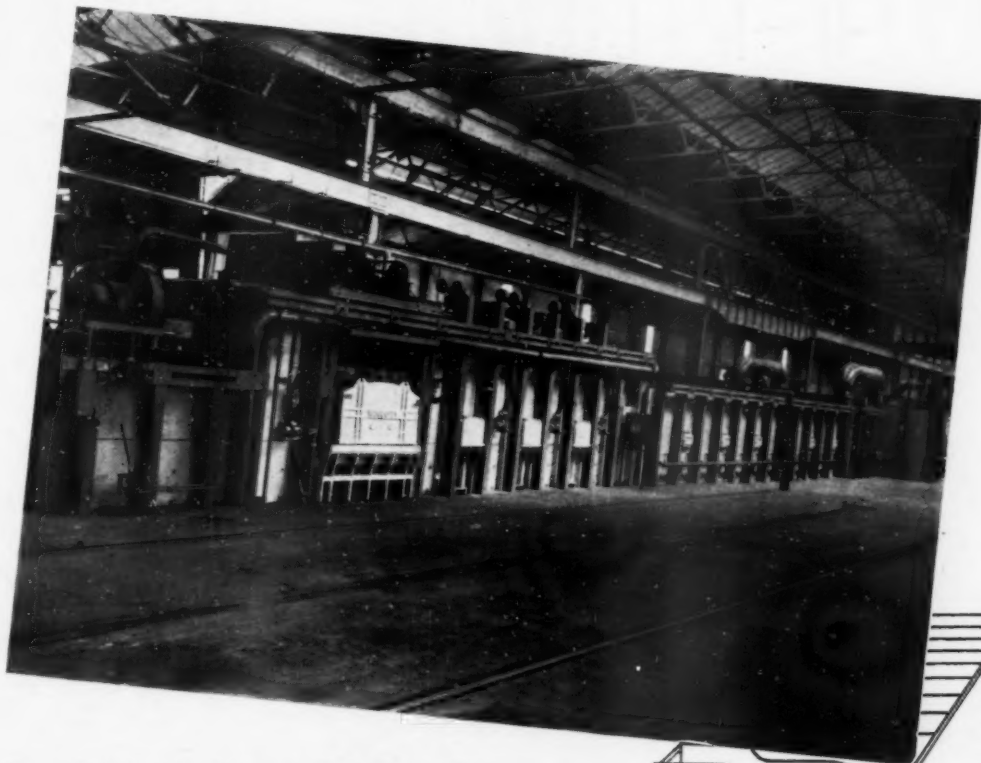
**BTH**

**RUGBY**

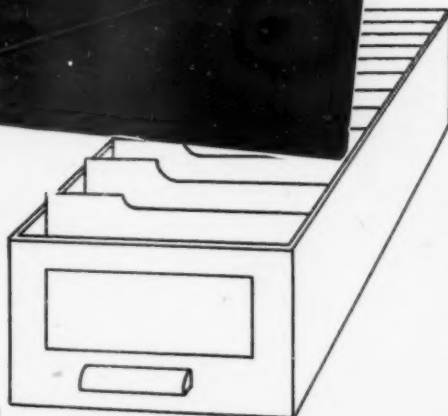
THE BRITISH THOMSON-HOUSTON COMPANY LIMITED, RUGBY, ENGLAND.

A3701

*one more from our records*



The photograph shows a Coke-Oven Gas-Fired Bogie-Type Furnace recently completed for the heating of steel blocks before pressing into wheels. The output is 12 tons per hour heated to 1250°C. The furnace is arranged for side discharge and works in conjunction with a mechanical manipulator. It is 120 ft. long, the bogies being 7 ft. 3 in. wide by 8 ft. long. Equipment includes two Needle Recuperators, electrically driven haulage mechanisms for the transfer cars and bogie return track, temperature recorder, gas-flow meters and pressure recorder.



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Harpers are at all times willing to co-operate with designers and manufacturers to provide, in Harper-Meehanite Castings, special mechanical and physical properties to meet particular service conditions.

This impellor casting is used in the very modern plant employed at the Glaxo laboratories in the making of streptomycin. Soundness, even distribution of metal and particularly good machineability are indicated requirements. Many firms are turning to Harper-Meehanite castings to provide satisfactory solutions to problems of manufacture.



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# STEIN

*Basic*

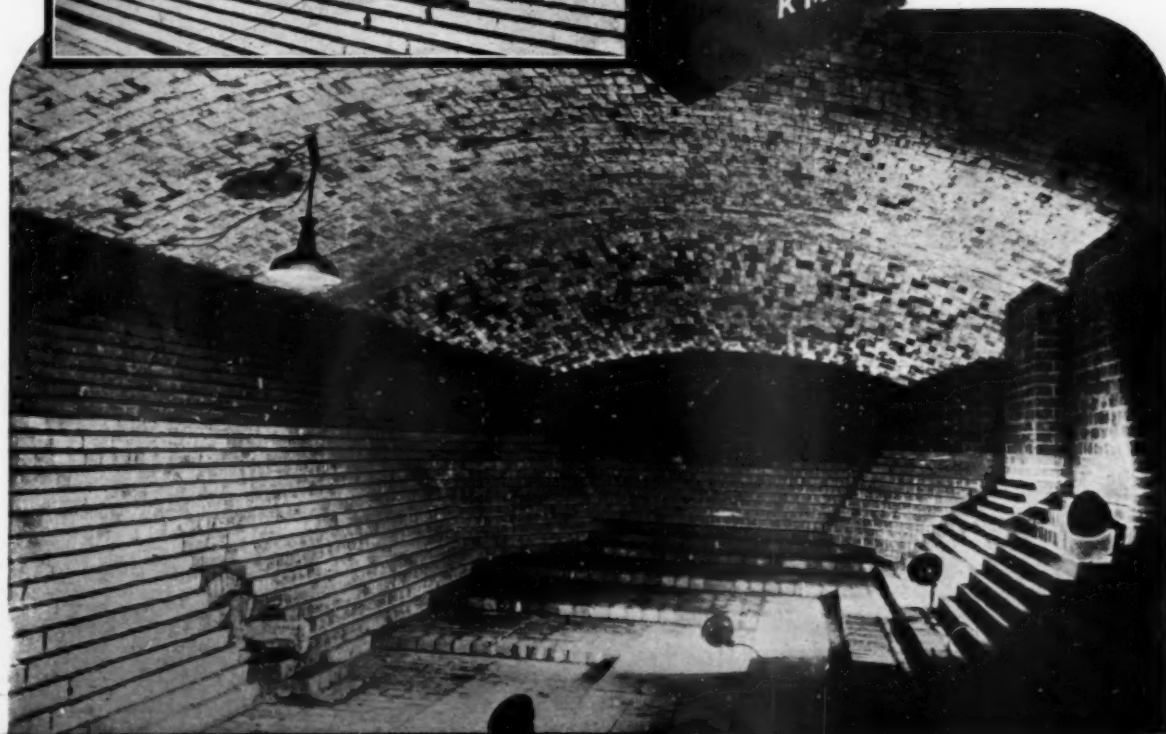
## REFRACTORIES



THE lower illustration shows a new 140-ton Basic Open Hearth Furnace. The Back and Front Wall construction and also the Wing Walls and Water Cooled Block are built with "Stein KM" Chrome Magnesite Brick. Hearth construction up to the slag line is Straight Magnesite Brick.

The smaller photograph shows the Front Wall Pillars and the Water Cooled Door Lintels.

This extended use of Basic Brick construction is strongly recommended to ensure maximum furnace operating time and reduced refractory costs.



JOHN G. STEIN & CO. LTD., BONNYBRIDGE, SCOTLAND

No. 10

# PREPARED BLACKING

(READY FOR USE)

*The World Famous Mould Wash  
for  
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**No. 7 NON-SILICA STEELMOL**

(For STEEL CASTINGS)

**"ALUMISH"**

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**ALL FOUNDRY SUPPLIES**

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*"Economical Metal Melting"*



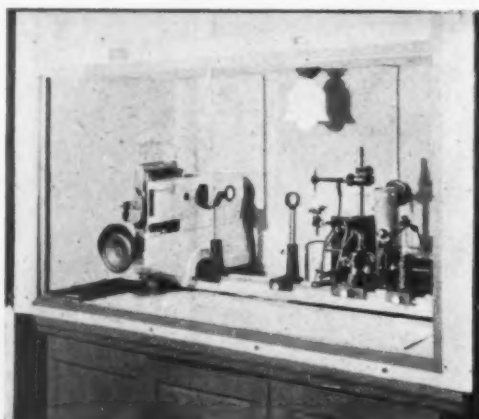
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*Established 1878*

# Refined **PIG IRON**

## Quality Control

Perfection in quality is Bradley's constant endeavour. Everything is done that can lead to better understanding and control of every conceivable factor in promoting the highest quality refined pig iron.



Bradley's Spectrographic  
Laboratory

Large Size Hilger Quartz  
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Bradley's spectrographic laboratory is the first in the country to operate exclusively in the routine control of refined iron and cast iron. It adds to their resources yet another of the modern tools provided by the physicist; a powerful weapon in the quality control of Bradley's refined pig iron.

*Makers of*

Spun Refined Cylinder Irons  
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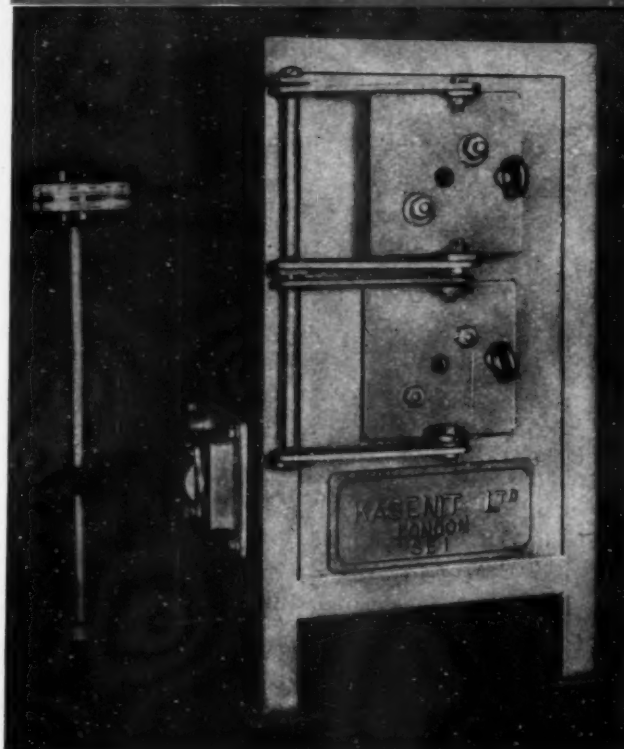
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Size of each chamber  $4\frac{1}{2}$ " wide  $\times$   $4\frac{1}{2}$ " high  $\times$   $7\frac{1}{2}$ " long.  
A Temperature up to  $1300^{\circ}\text{C}$ . in 20 mins.



BENCH TYPE GAS FIRED MUFFLE FURNACE IN  
TWO SIZES:  $5"$  wide  $\times$   $2"$  high  $\times$   $9"$  long } TEMP.  
 $6"$  wide  $\times$   $5"$  high  $\times$   $12"$  long }  $1000^{\circ}\text{C}$ .

*Standard Furnaces for a wide range  
of Heat Treatments are designed  
and manufactured by*

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reconstruction line**



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## CHROMEND B.B.

For Molybdenum Bearing. 18/8 Steels.

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on our Laurels*

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steel made.**

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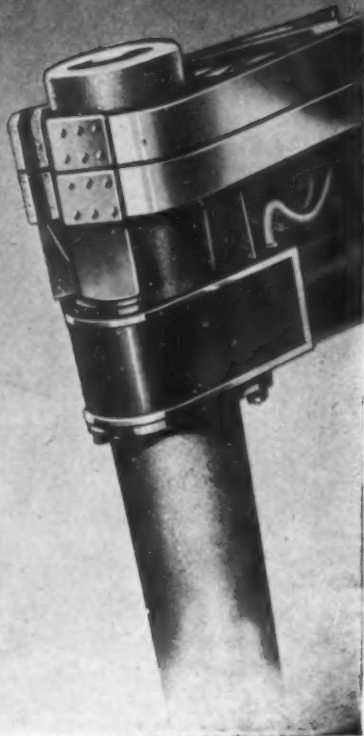
**Resistance to Thermal shock.**

**Maximum furnace output.**

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# ETHER-WHEELCO

## ELECTRONIC CONTROLS

**T**HESE instruments operating on the Electronic principle are made in England for sale throughout the world by the Ether organisation. They were originally developed by the Wheelco Instrument Company of Chicago, U.S.A., and are made by arrangement with them. Over 50,000 of these instruments have been sold and are in use all over the world. The whole of the technical progress and "know how" possessed by Wheelco has been made available to Ether, who themselves have been engaged in the manufacture of Electronic equipment for the last 24 years. The combination of the two companies has produced instruments of unexcelled technical and mechanical construction.

Fig. 1 shows the way in which the science of electronics is used to automatically control temperatures, with the speed of light, great accuracy and no interference with the measuring system. A light aluminium flag "C" passes between two coils "A" of the electronic system, when the flag enters the sphere of influence of the coils a movement of a few thousandths of an inch is sufficient to switch the control system off and on. By moving the coils attached to the pointer "B" the control position can be readily adjusted.

Fig. 2. shows the "CAPACITROL" Automatic Temperature Controller capable of controlling electric, gas and oil-fired furnaces and apparatus utilising the On-Off or By-Pass system of control.

Other types are made giving two position and proportional control, these are known as the "MULTRONIC" and "PROPORTIONAL CAPACITROL."

All these instruments utilise electronics to automatically control temperatures with the speed of light, great accuracy and no interference with the measuring system. They are faster, simpler and more accurate than the Chopper Bar type formerly used.

*Send for descriptive List No. 447.*



Fig. 2  
Ether-Wheelco "Capacitrol" Automatic Temperature Controller.

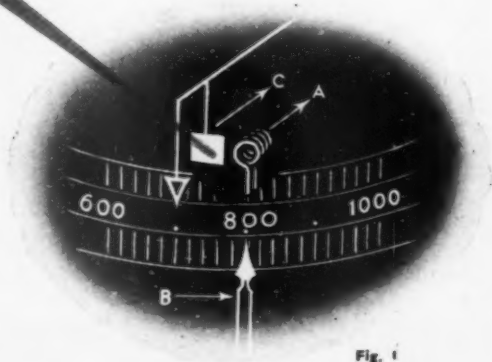


Fig. 1

# ETHER LIMITED

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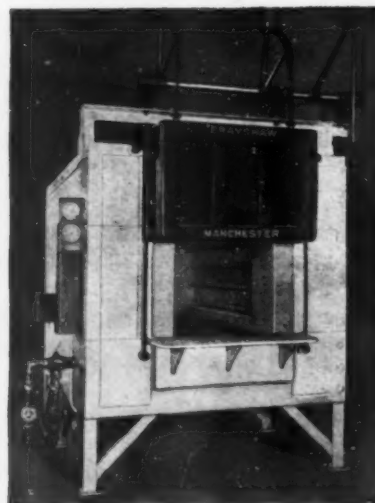
# BRAYSHAW ELECTRIC FURNACES

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**THE AMERICAN ELECTRIC FURNACE CO.,  
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★ These furnaces, incorporating the latest American practice, are manufactured at our Manchester Works and include the following standard ranges:—

**HIGH TEMPERATURE FURNACES FOR HIGH-SPEED STEEL.  
OVEN FURNACES FOR GENERAL HEAT-TREATMENT.  
AIR CIRCULATION FURNACES FOR TEMPERING, ETC.  
SALT BATH FURNACES.  
POT FURNACES FOR MELTING LEAD, ALUMINIUM &  
WHITE METAL ALLOYS.**



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SUPPLIED ON REQUEST.

**BRAYSHAW**  
**FURNACES & TOOLS LTD**  
BELLE VUE WORKS · MANCHESTER 12



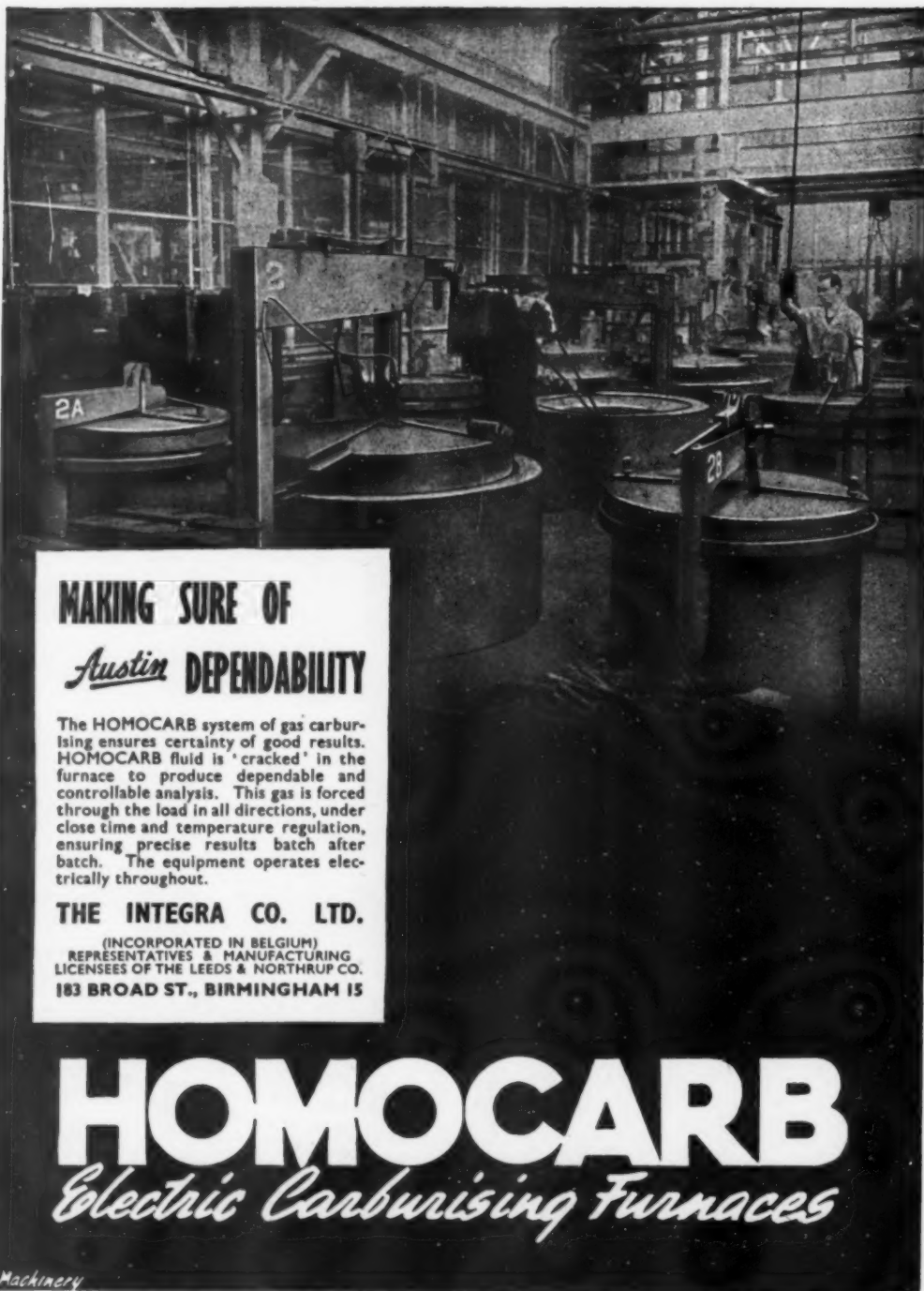


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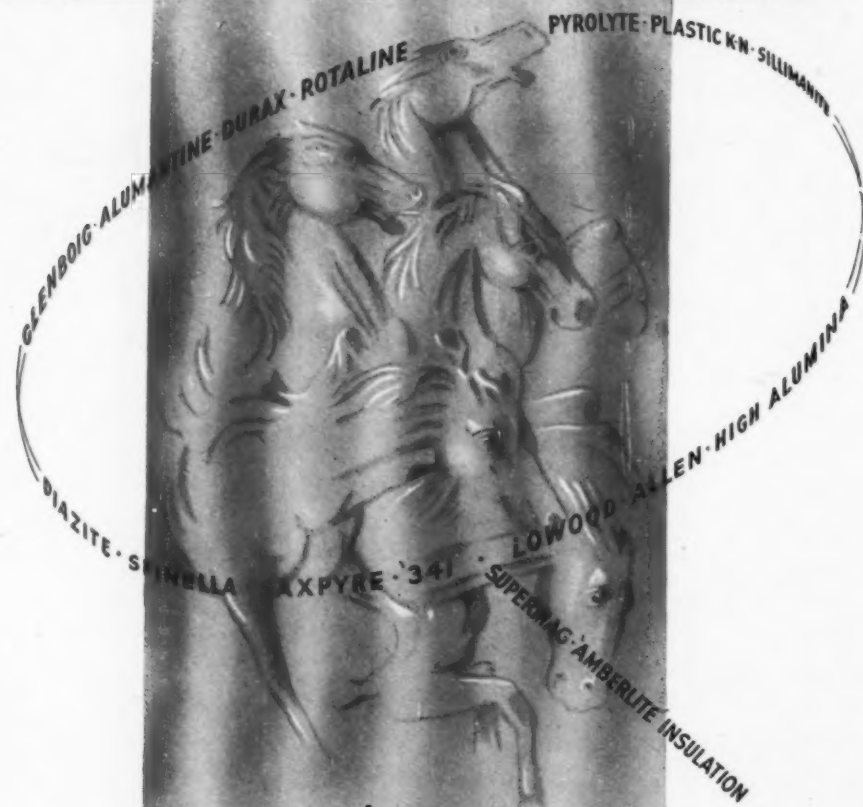
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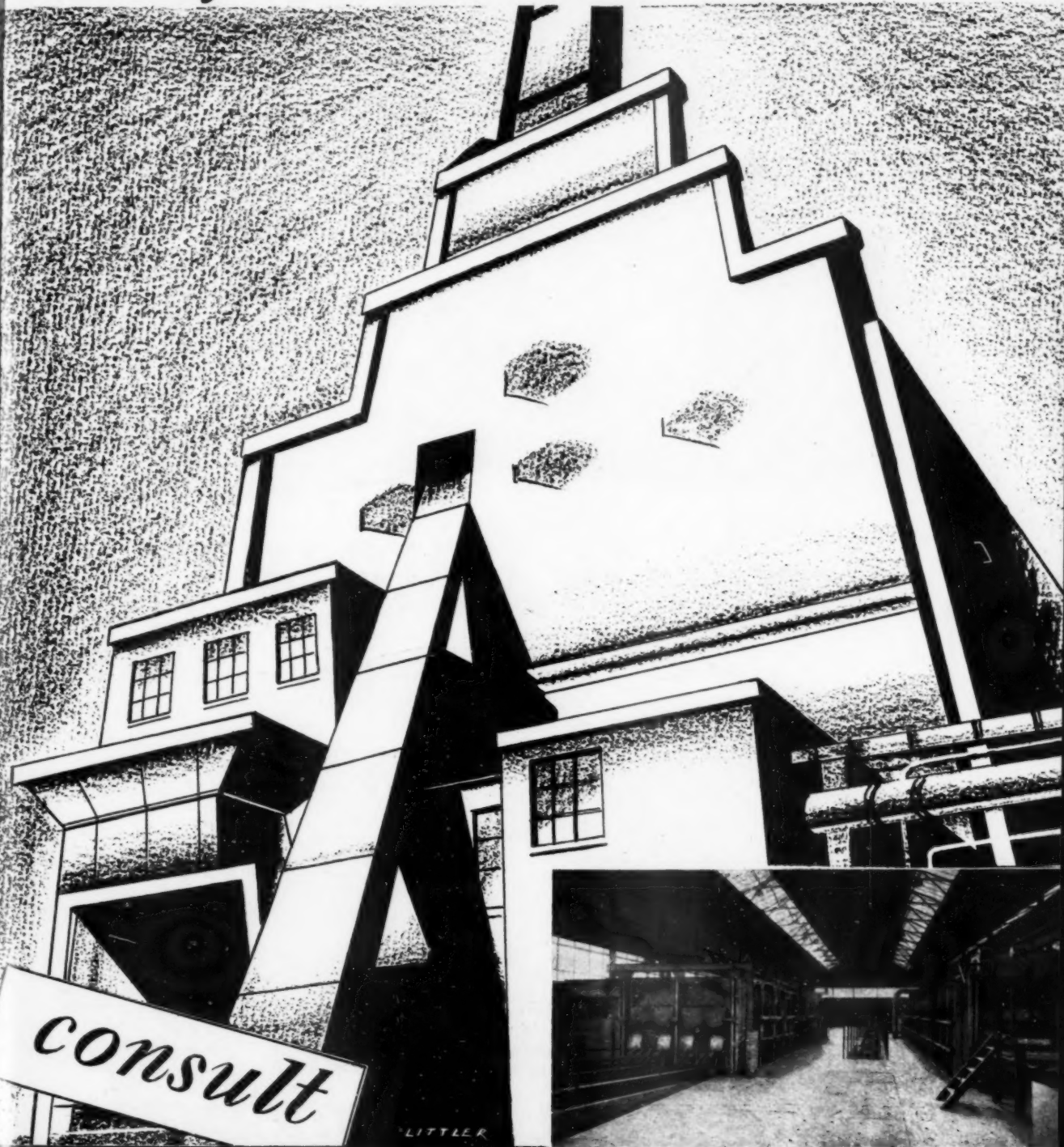
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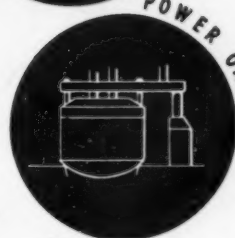
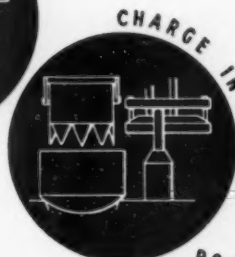
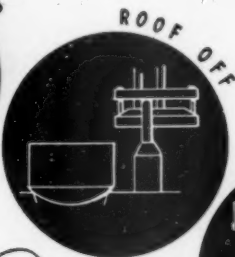
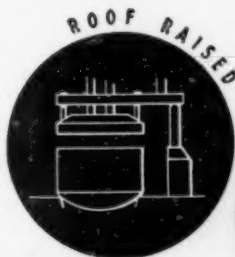
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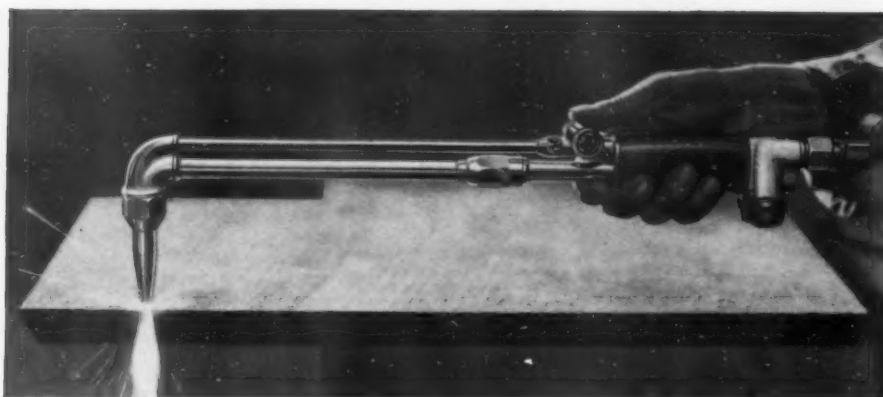
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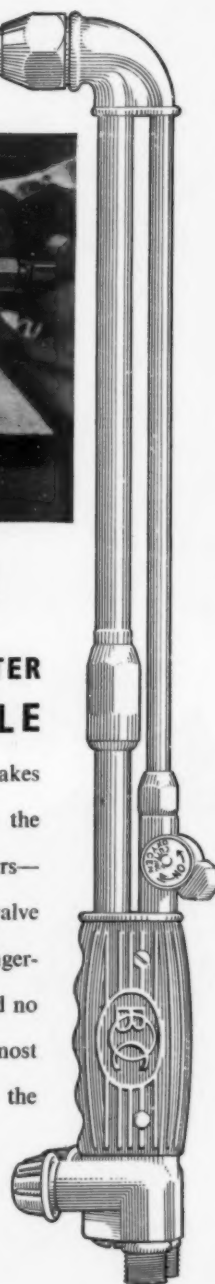
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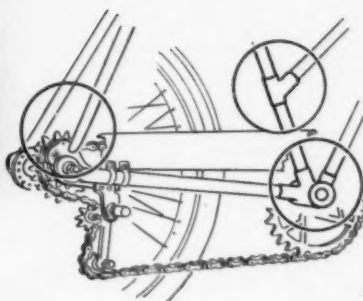
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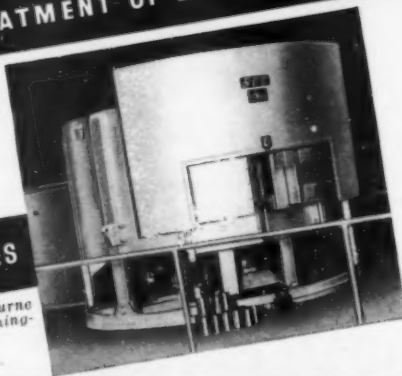


**HEAT TREATMENT OF LIGHT ALLOYS**

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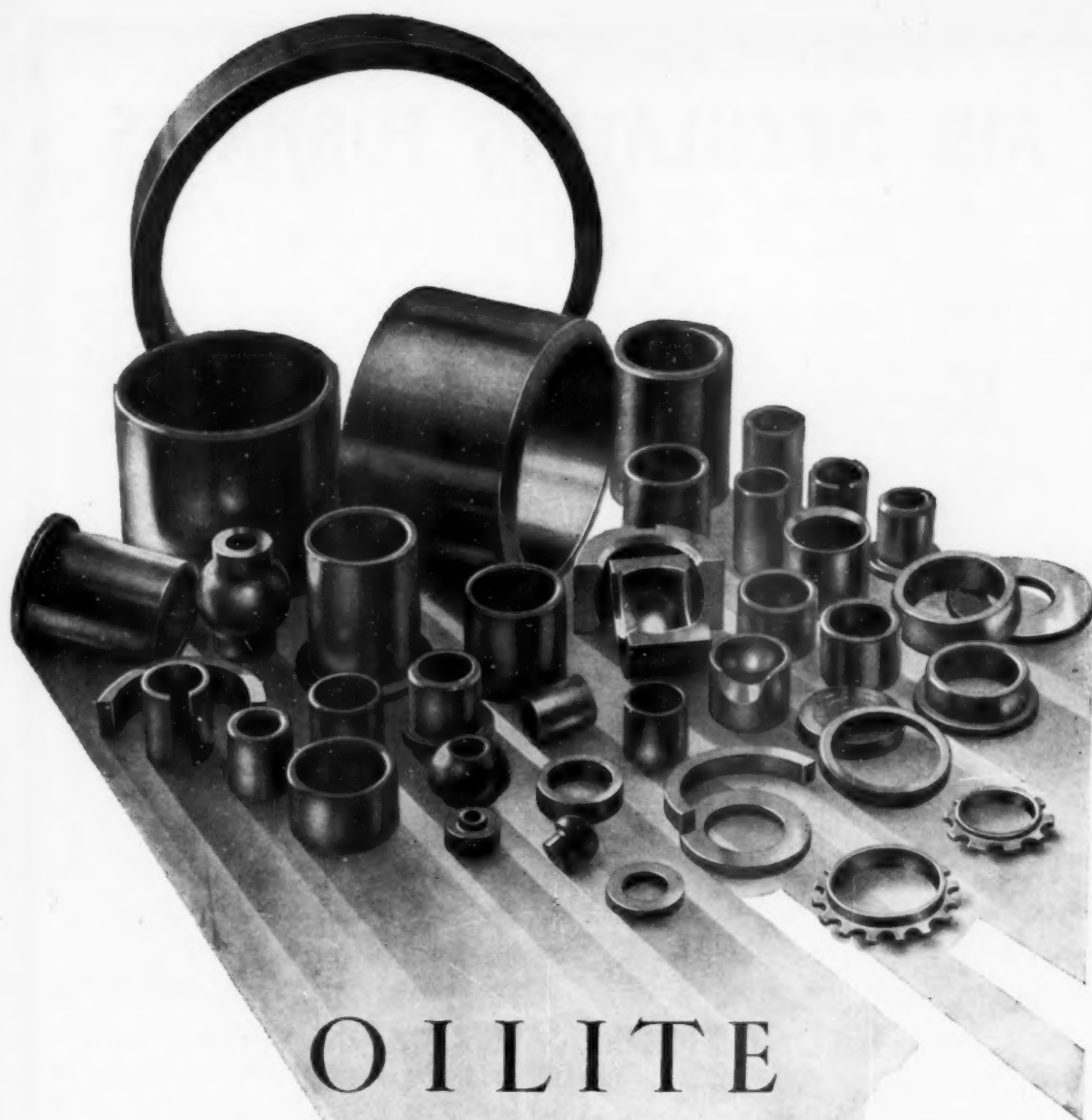
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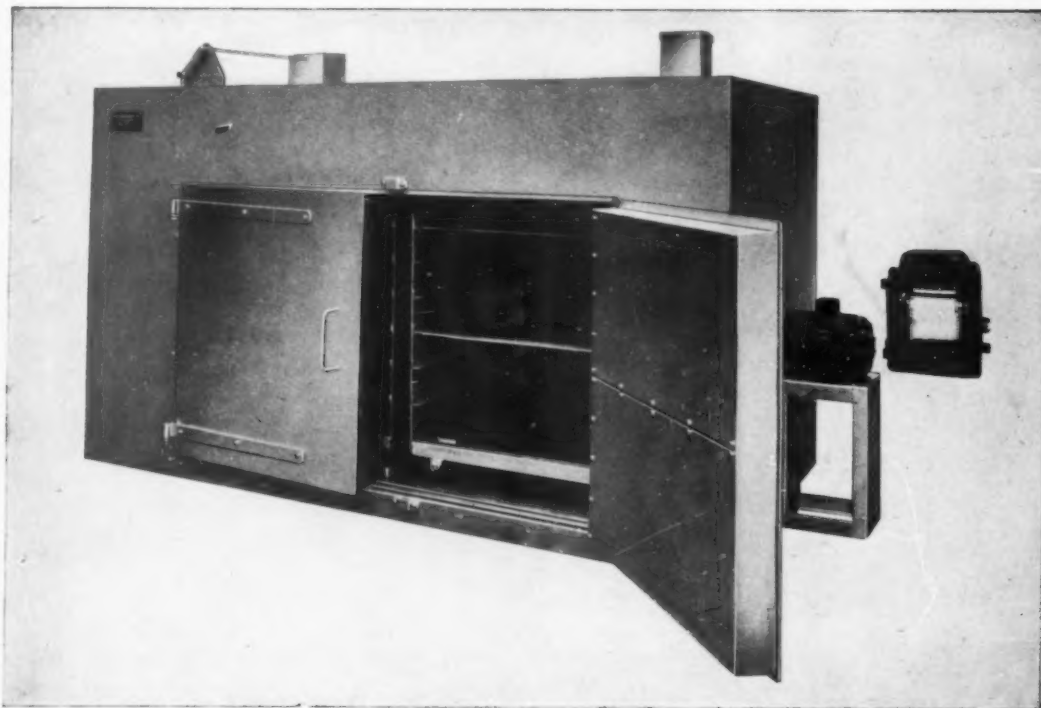
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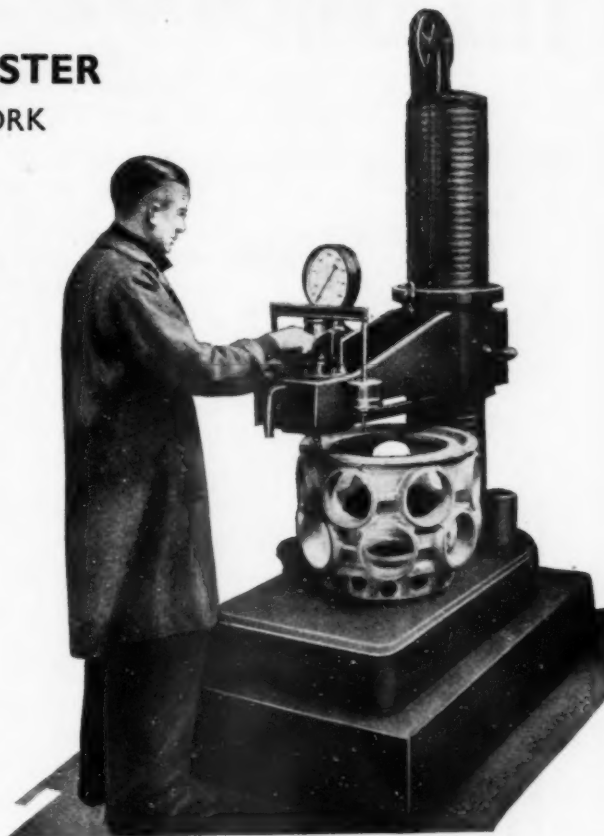
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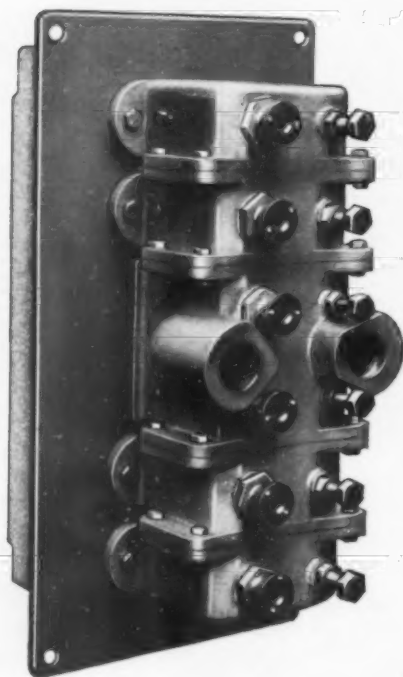
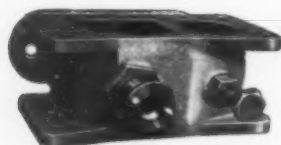
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# METALLURGIA

## *The British Journal of Metals*

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Readers are invited to submit articles for publication in the editorial pages; photographs and/or drawings suitable for reproduction are especially welcome. Contributions are paid for at the usual rates. We accept no responsibility in connection with submitted manuscript. All editorial communications should be addressed to The Editor, "Metallurgia," 31, King Street West, Manchester, 3.

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# METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING THE "METALLURGICAL ENGINEER."

FEBRUARY 1949

Vol. XXXIX No. 232

## Spitfires to Prefabs

**T**HE changeover from swords to ploughshares and from spears to pruning hooks was expected to be taken in its stride by the steel industry on the cessation of hostilities. There was, of course, some doubt as to the ability of the steel-making concerns to produce sufficient steel to satisfy all demands, made up, as these were, of normal replacements, an expanding export trade in steel consuming industries and much repair and replacement work long delayed by the need of the war machine for all the steel it could obtain. On the other hand many must have wondered how the aluminium industry would tackle the converse problem, namely that of utilising, to the full, a fabricating industry which had been greatly expanded to meet the needs of the wartime aircraft industry. True, many peacetime products had not been made for several years, and, in fact, the patriotically-minded public had surrendered much of its domestic aluminium-ware for conversion into Spitfires — or at least to turn into D.T.D.424. Nevertheless, it was clear that the productive capacity of the industry was such that the wastage of its pre-war products could be made good in a comparatively short time, and that, if the plants were to be kept in full operation, the field of application of aluminium alloys would have to be appreciably enlarged. The extent to which this has been accomplished is cause for pride, though not complacency, on the part of the industry.

It must be admitted that certain factors have been of considerable assistance in attaining success. In the first place, the Government's temporary housing scheme — as part of which 55,000 prefabricated houses, each utilising  $1\frac{1}{2}$  tons of aluminium, had been completed by the middle of last year — helped to tide over what might otherwise have been a very difficult period and at the same time served to demonstrate the qualities of aluminium alloys for building purposes. It should be noted, however, that when the Government's aluminium "prefab" programme came to an end, the capacity so freed was taken up again in a few weeks. Secondly, the shortage of steel has enabled the advocates of aluminium to put their belief to the test on a much greater scale than would normally have been likely.

Without doubt, it is in the field of structural engineering that the greatest progress has been made in the adoption of aluminium. The fact that there are available aluminium alloys with tensile strengths equal to that of mild steel does not, of course, mean that direct substitution of one for the other can be made. On the contrary, the difference in elastic modulus has necessitated the design of new structural sections. For instance, an aluminium beam of similar shape to a steel beam would be about one-third the weight of the latter for the

same strength but, in order to attain equal deflection characteristics, the change in shape and size of the beam would bring the weight up to half that of the equivalent steel beam. Nevertheless considerable headway has been made, particularly in the building industry where the use of aluminium for roof structures is increasing in popularity in spite of the disadvantages of high cost and low elastic properties. For certain purposes, such as in chemical works, engine sheds and the like, the high corrosion resistance and non-staining characteristics of aluminium are of considerable advantage. In hot climates, too, the high reflectivity of aluminium roofing helps to keep down the temperature inside the building, and it is of interest to note that a British light alloy structural engineering firm has recently obtained a ten-year contract for the supply of aluminium houses to India. Nor has the use of aluminium in building been confined to structural members; aluminium windows, rainwater fittings and electrical conduit tubing are firmly established, and a start has been made in popularising aluminium kitchen sinks, both cast and fabricated from sheet.

Lest it should be imagined that building is the only branch of structural engineering using aluminium, mention should be made of bridge-building. The first aluminium bridge in this country, the twin leaf trunnion bascule bridge over the Hendon Dock Junction Gateway, at Sunderland, which was opened recently, evoked considerable interest. The importance of light weight in a moving bridge is obvious and some appreciation of the saving in weight which may be effected is given by an American railway bridge in which three spans are made of steel and the fourth aluminium. The aluminium span is less than half the weight of the equivalent steel span.

It is, of course, in the field of transport that the lightness of aluminium is utilised to the best advantage. A certain American steel-making concern, manufacturing high-strength structural steel, features in its advertisements a massive shapeless creature, labelled "Dead Weight," sitting on top of a motor truck with the caption — "Can you afford to give him a free ride every trip?" The increasing use of light alloys for engine parts and coachwork, in order to reduce dead-weight, has resulted in the road transport industry being, after building, the second largest consumer of aluminium alloys. In shipbuilding, too, some progress has been made with small craft.

As far as Britain is concerned, there is still one transport stronghold in which a bridge-head has yet to be established, namely the railways. In view of the use which has been made of aluminium alloys on railway systems abroad, it is surprising that it is only in the last month or two that an announcement has been made of the intention to use aluminium in the construction of

certain experimental passenger coaches. Since the war, large numbers of steel goods trucks, suitable for carrying coal, etc., have been made and although aluminium trucks have been suggested there are no signs of any steps being taken in that direction. The French railways have tried trucks constructed almost entirely of aluminium — steel being retained for wheel rims, axles, springs and couplings and for the soles of brake shoes. After twelve months service, some bulging was observed, but this was rectified by suitable bracing. One of the prototypes was involved in a collision with loaded steel trucks and although the sheet metal was punctured,

the chassis withstood the shock at least as well as a steel chassis.

If the progress already achieved is to be maintained, there must be an adequate supply of raw materials. As the home production of virgin metal is only of the order of 30,000 tons per annum, a considerable amount has to be imported, in spite of the widespread use of secondary aluminium. The cost of imported material must, of course, be placed on the debit side of the national economy, but the figure is not very large when it is compared with the value of finished goods with a high British labour content.

## SCIENCE AND INDUSTRY

Of importance to all firms and individuals interested in the manufacture and use of iron and steel, but not themselves makers or processors, is the announcement that the British Iron and Steel Research Association will now admit them to a newly established category of Associate Membership.

B.I.S.R.A.'s activities since its formation in 1945 have largely concerned the making and shaping and the properties of iron and steel, and have clearly shown how researches of this nature relate closely at one end with the industry's suppliers of raw materials and capital equipment, and at the other with the users of its products. Co-operation at each end has been close, as, for example, in work on the design of new plant which has involved suppliers, and in work on a wide variety of corrosion problems which has involved users.

The present step, therefore, carries this co-operation on a stage further, and gives firms and individuals of allied or interested industries a more direct opportunity of influencing the Association's research programme (at present numbering some 400 projects), and of having access to research results at the earliest possible moment. For example, Associate Members will receive research reports and will be able to attend the technical Conferences which are a feature of B.I.S.R.A.'s information methods, numbering about 20 yearly and covering almost every aspect of the Association's work.

The organisation of B.I.S.R.A. into six largely autonomous Divisions enables Associate Members to restrict their participation to selected fields, if they wish. Trade Associations are not eligible, and in the fields of coke and refractories such close collaboration between B.I.S.R.A. and the respective Research Associations already exists, that membership by firms in those industries would serve little practical purpose.

Associate Members will be drawn, it is expected, from a wide range of other industries, providing another link in the essential bond between industry and science.

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## THE INSTITUTE OF METALS

### W. H. A. Robertson Medal and Premium

As was announced at the 1948 Annual General Meeting of the Institute, Messrs. W. H. A. Robertson & Co., Ltd., of Bedford, offered to the Institute of Metals a medal and premium to be awarded for the encouragement of the publication of papers dealing with the engineering side of non-ferrous metal production. The Council of the Institute gratefully accepted this offer, and designs for a bronze medal, 3 in. in diameter, have been approved.

The W. H. A. Robertson medal and premium will be awarded annually by the Council of the Institute to the author or authors of the paper adjudged to be of the highest merit contributed to the *Journal of the Institute of Metals* on engineering aspects of non-ferrous metallurgy. No award will be made in any year when the Council is satisfied that no paper has been published which is of such merit as to justify the award.

For the first award, the Medal Committee of the Institute will consider papers published in the Institute's *Journal* from March, 1948, to August, 1949, inclusive. Thereafter the annual award will be made in respect of papers published in the *Journal of the Institute of Metals* covering the annual issues from September to August, inclusive.

### Award of Institute Medals for 1949

THE Institute of Metals Medal (in platinum) for 1949, has been awarded to Dr. William Hume-Rothery, F.R.S., in recognition of his outstanding contributions to the science of non-ferrous metallurgy. The President will present the medal at the Annual General Meeting of the Institute in the Hall of the Institution of Mechanical Engineers, on the morning of Wednesday, 30 March 1949. The medal is placed at the disposal of the Council of the Institute, annually, by The Mond Nickel Co., Ltd.

### Suspension of Entrance Fee

The Council of the Institute has resolved to suspend the entrance fee with effect from 1 January 1949, for a period of two years, after which the matter will be reviewed. This decision will be important for intending applicants for membership, who should address enquiries to the Secretary at 4, Grosvenor Gardens, London, S.W.1.

### 1949 Autumn Meeting in Paris

The 1949 Meeting of the Institute of Metals will be held in Paris in September. The dates have not yet been definitely fixed, but further particulars will be published at an early date.



# Effect of Variation in Silicon Content on the Properties of Silicon - Manganese Spring Steel

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(A communication from the Research & Development Department, The United Steel Companies Limited.)

*In the specification for silicon-manganese spring steel, B.S.S. 970(1947)-En 45 and En 45A, the lower limit of silicon content is placed at 1.5%. In this article are given the results of an investigation on the effect of varying the silicon content between 0.5 and 2.64%, on susceptibility to decarburisation, tempering, hardenability and mechanical properties, including fatigue. It is concluded that the range of 1.5-2.0%, quoted in the specification is probably an optimum since decrease in silicon below 1.5% increases the susceptibility to decarburisation, whilst increase in silicon beyond the upper limit is liable to result in inferior notch toughness and fatigue strength.*

THE view is taken in some quarters that a silicon content below the lower limit of 1.5% as specified in B.S.S. 970 (1947) for En 45 and 45A steels, is not detrimental to the properties of the steel. In order to investigate this point and with the object of determining optimum silicon content, tests were carried out, including susceptibility to decarburisation, response to tempering, hardenability, mechanical and fatigue tests on a series of experimental steels made in an 18 lb. high-frequency furnace. The analyses of the steels which vary in silicon content from 0.5 to 2.64% are given in Table I. In order to provide sufficient material to cover the full range of tests, it was necessary to duplicate each ingot. It will be noted however that the difference in composition between the duplicate ingots is of a relatively small order.

TABLE I.—ANALYSES OF STEELS.

| Steel No. ..  | 1     | 2     | 3     | 4     | 5     | 6     | 7     |
|---------------|-------|-------|-------|-------|-------|-------|-------|
| Analysis:     |       |       |       |       |       |       |       |
| Carbon ..     | 0.56  | 0.57  | 0.57  | 0.56  | 0.59  | 0.58  | 0.58  |
| Manganese ..  | 0.86  | 0.91  | 0.91  | 0.88  | 0.92  | 0.92  | 0.96  |
| Silicon ..    | 0.50  | 1.00  | 1.32  | 1.65  | 1.98  | 2.32  | 2.64  |
| Sulphur ..    | 0.031 | 0.031 | 0.035 | 0.034 | 0.030 | 0.031 | 0.030 |
| Phosphorus .. | 0.033 | 0.031 | 0.032 | 0.033 | 0.033 | 0.031 | 0.032 |
| Steel No. ..  | *8    | *9    | *10   | *11   | *12   | —     | *13   |
| Analysis:     |       |       |       |       |       |       |       |
| Carbon ..     | 0.57  | 0.58  | 0.58  | 0.60  | 0.58  | —     | 0.55  |
| Manganese ..  | 0.86  | 0.90  | 0.91  | 0.95  | 1.02  | —     | 1.04  |
| Silicon ..    | 0.475 | 1.02  | 1.32  | 1.63  | 1.98  | —     | 2.30  |
| Sulphur ..    | 0.032 | 0.034 | 0.033 | 0.035 | 0.025 | —     | 0.027 |
| Phosphorus .. | 0.031 | 0.031 | 0.032 | 0.032 | 0.029 | —     | 0.029 |

\* In order to provide sufficient material for fatigue tests, it was found necessary to duplicate the majority of the steels.

## Susceptibility to Decarburisation

It is generally well known that decarburisation has a marked deleterious effect on fatigue properties particularly under conditions of bending where the maximum applied stress is at the surface, i.e., in the decarburised layer. Carburisation on the other hand produces a marked increase in fatigue strength under the same condition of stress. The susceptibility to decarburisation is therefore a matter of first importance in considering any steel to be used in the manufacture of a spring, unless steps are taken to remove the decarburised layer.

In selecting the conditions for the decarburisation tests, consideration was given to the practical heating operations consisting essentially of two, one at a

temperature of about 1,150° C. adopted for heating of the material for rolling to the desired section, and the other at a temperature of 1,000° C. used for forming and in some cases for subsequent hardening.

For the tests at 1,150° C., the specimens were heated for periods of 1, 2 and 4 hours in an atmosphere containing 7% carbon dioxide, 12% oxygen and 81% nitrogen.

In the tests at 1,000° C. a gas atmosphere containing 16% carbon dioxide, 3.5% oxygen and 80.5% nitrogen was adopted, the specimens being heated for periods of 5, 15 and 30 minutes.

The selection of these atmospheres was based on those used respectively in a billet-heating furnace and in a spring-coiling furnace.

The 2½ in. square ingots were forged to 1½ in. dia. for hardenability tests and the remainder to ¾ in. dia.

Samples of each steel, 1½ in. in length, were smooth ground to 0.500 in. in dia. They were heated for the periods of time and temperatures stated above, in a laboratory furnace in the synthetic gas mixtures. Measurements were made of the depth of decarburisation, by means of a microscope, the depth being assessed on the basis of the total affected structure. The results of

TABLE II.—SPECIMENS HEATED AT 1,150° C. IN AN ATMOSPHERE AT 7% CO<sub>2</sub>, 12% O<sub>2</sub>, 81% N<sub>2</sub>.

| Steel No.       | Time in Furnace Hours | Depth of Decarburisation Ins. |
|-----------------|-----------------------|-------------------------------|
| 1<br>(0.5% Si)  | 1                     | 0.040                         |
|                 | 2                     | 0.060                         |
|                 | 4                     | 0.085                         |
| 2<br>(1.0% Si)  | 1                     | 0.034                         |
|                 | 2                     | 0.053                         |
|                 | 4                     | 0.080                         |
| 3<br>(1.32% Si) | 1                     | 0.032                         |
|                 | 2                     | 0.050                         |
|                 | 4                     | 0.080                         |
| 4<br>(1.65% Si) | 1                     | 0.045                         |
|                 | 2                     | 0.055                         |
|                 | 4                     | 0.085                         |
| 5<br>(1.98% Si) | 1                     | 0.025                         |
|                 | 2                     | 0.050                         |
|                 | 4                     | 0.075                         |
| 6<br>(2.32% Si) | 1                     | 0.050                         |
|                 | 2                     | 0.055                         |
|                 | 4                     | 0.085                         |
| 7<br>(2.64% Si) | 1                     | 0.050                         |
|                 | 2                     | 0.065                         |
|                 | 4                     | 0.080                         |

TABLE III.—SPECIMENS HEATED AT 1,000° C. IN AN ATMOSPHERE  
AT 16.0% CO<sub>2</sub>, 3.5% O<sub>2</sub>, 80.5% N<sub>2</sub>

| Steel No.       | Time in Furnace Minutes | Depth of Decarburisation Ins. |
|-----------------|-------------------------|-------------------------------|
| 1<br>(0.32% Si) | 5                       | 0.005                         |
|                 | 15                      | 0.009                         |
|                 | 30                      | 0.010                         |
| 2<br>(1.0% Si)  | 5                       | 0.004                         |
|                 | 15                      | 0.009                         |
|                 | 30                      | 0.011                         |
| 3<br>(1.32% Si) | 5                       | 0.005                         |
|                 | 15                      | 0.008                         |
|                 | 30                      | 0.010                         |
| 4<br>(1.65% Si) | 5                       | 0.004                         |
|                 | 15                      | 0.008                         |
|                 | 30                      | 0.010                         |
| 5<br>(1.98% Si) | 5                       | 0.005                         |
|                 | 15                      | 0.007                         |
|                 | 30                      | 0.009                         |
| 6<br>(2.32% Si) | 5                       | Trace                         |
|                 | 15                      | 0.005                         |
|                 | 30                      | 0.008                         |
| 7<br>(2.64% Si) | 5                       | Trace                         |
|                 | 15                      | Trace                         |
|                 | 30                      | 0.006                         |

these measurements are given in Tables II and III and represented graphically in Figs. 1 to 4.

The variation in degree of decarburisation with period of heating at a temperature of 1,000° C. of the various samples (Fig. 1) showed some interesting features. The steels containing up to 1.98% silicon were decarburised at a rate which decreased continuously with increase in

heating period, the difference in degree of decarburisation in these steels being relatively small. The steel containing 2.32% silicon showed no appreciable decarburisation until the period of heating was extended to 15 min. Between 5 and 15 min. and between 15 and 30 min. the rate was greater than that of the lower silicon steels although the total decarburisation after 30 min. was least in the case of the 2.32% silicon steel. The highest silicon steel (2.64%) showed no appreciable decarburisation on heating for 15 min. but the rate of decarburisation between 15 and 30 min. was greater than the corresponding rates for the remaining steels. After 30 min. heating, the 2.64% silicon steel showed the lowest total decarburisation. The results indicated that with more extended periods of heating, the difference in degree of decarburisation of the seven steels would decrease, the curves tending to converge with increase in time beyond 15 min.

Considering the results of the tests at a temperature of 1,000° C., on the basis of variation in degree of decarburisation with silicon content for fixed periods of heating (Fig. 2) an increase in silicon content above 1.65% for heating times of 15 and 30 min. and above 2.0% for a heating time of 5 min., was associated with a marked decrease in depth of decarburisation.

In the tests at a temperature of 1,150° C. all the steels showed a somewhat similar increase in the degree of decarburisation with increase in time of heating in the

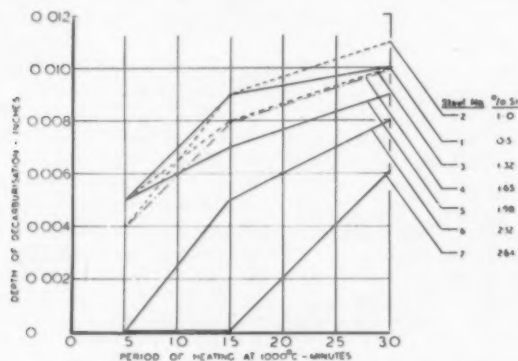


Fig. 1.—Decarburisation of steels at 1,000° C.

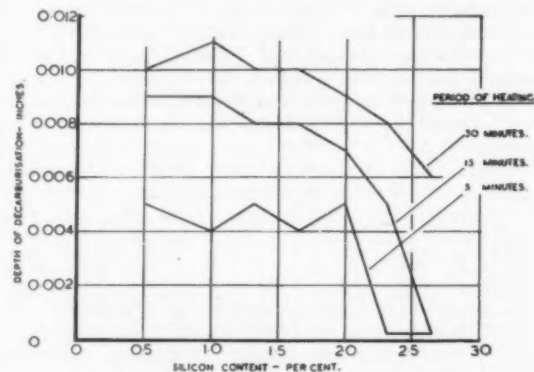


Fig. 2.—Decarburisation of steels at 1,000° C.

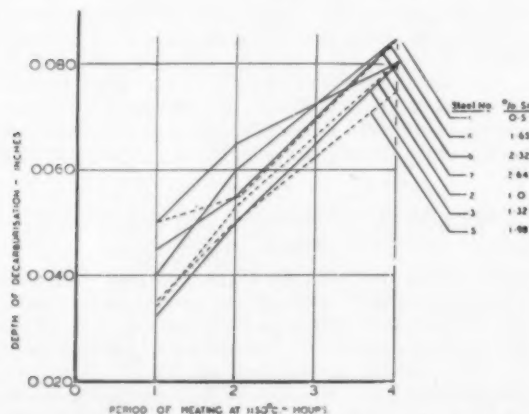


Fig. 3.—Decarburisation of steels at 1,150° C.

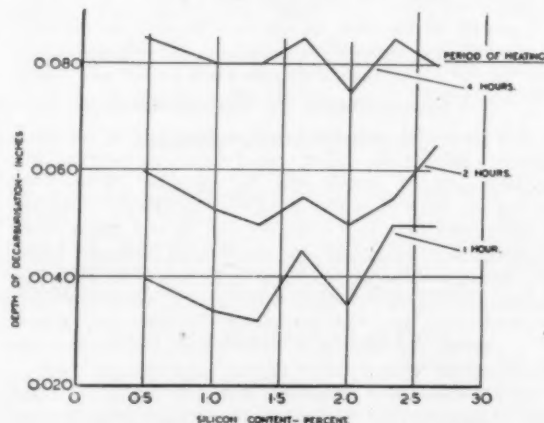


Fig. 4.—Decarburisation of steels at 1,150° C.

TABLE IV.—HARDNESS DETERMINATIONS ON SAMPLES OIL QUENCHED FROM A TEMPERATURE OF 800° TO 950° C.

| Reheating Temperature<br>° C. | Steel Numbers               |                 |                 |                 |                 |                 |                 |
|-------------------------------|-----------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                               | 1<br>(0.50% Si)             | 2<br>(1.00% Si) | 3<br>(1.32% Si) | 4<br>(1.65% Si) | 5<br>(1.98% Si) | 6<br>(2.32% Si) | 7<br>(2.64% Si) |
|                               | Hardness, H <sub>D</sub> 30 |                 |                 |                 |                 |                 |                 |
| 800                           | 734                         | 576             | 777             | 449             | 409             | 286             | 520             |
| 825                           | 741                         | 680             | 792             | 567             | 517             | 345             | 769             |
| 850                           | 768                         | 802             | 791             | 805             | 787             | 809             | 814             |
| 875                           | 769                         | 790             | 775             | 801             | 779             | 814             | 805             |
| 900                           | 737                         | 767             | 743             | 788             | 750             | 802             | 803             |
| 925                           | 672                         | 703             | 729             | 745             | 655             | 790             | 773             |
| 950                           | 685                         | 618             | 689             | 671             | 508             | 743             | 766             |

range of 1 to 4 hours (Fig. 3). There was no definite variation in the degree of decarburisation with increase in silicon content (Fig. 4).

#### Quenching Tests.

In order to determine the quenching temperature which produces maximum hardness, specimens  $\frac{1}{2}$  in. dia. and 1 in. long were oil quenched at intervals of temperature of 25° C. within the range 800° to 950° C. The results of diamond pyramid hardness tests are given in Table IV. The maximum hardness of most of the steels occurred on quenching from a temperature of 850° C.

The maximum hardness of the remaining steels was obtained after quenching from 875° C. but in these cases the hardness differed only slightly from that of the respective specimens quenched from 850° C. The steel containing 0.50% silicon had the lowest hardness of 769 H<sub>D</sub>/30, the hardness of the remaining steels being within the range 787 to 814 H<sub>D</sub>/30, the two steels of highest silicon content giving the highest hardness.

#### Tempering Tests.

In order to determine the response of the various steels to tempering, specimens  $\frac{1}{2}$  in. dia. and 1 in. long were first normalised at a temperature 80° C. above the A<sub>c3</sub> point, determined dilatometrically, then quenched from a temperature 70° C. above the A<sub>c3</sub> point. The temperature of the A<sub>c3</sub> point and selected normalising and hardening temperatures were as follows:—

| Steel No. | Silicon Content | A <sub>c3</sub> Temperature | Normalising Temperature | Hardening Temperature |
|-----------|-----------------|-----------------------------|-------------------------|-----------------------|
|           | per cent.       | ° C.                        | ° C.                    | ° C.                  |
| 1         | 0.50            | 785                         | 865                     | 855                   |
| 2         | 1.00            | 790                         | 870                     | 860                   |
| 3         | 1.32            | 795                         | 875                     | 865                   |
| 4         | 1.65            | 805                         | 885                     | 875                   |
| 5         | 1.98            | 810                         | 890                     | 880                   |
| 6         | 2.32            | 780                         | 860                     | 830                   |
| 7         | 2.64            | 810                         | 890                     | 880                   |

The temperature of the A<sub>c3</sub> point increased progressively from 785° C. to 810° C. with increase in the silicon content from 0.50 to 1.98% and remained at

810° C. with 2.64% silicon, the temperature for the 2.32% silicon steel being relatively low.

The hardening temperatures, based on the A<sub>c3</sub> temperature, corresponded closely with those based on maximum hardness values.

The oil quenched specimens were tempered for 10 min. at 400° C. and at increments of temperature of 25° C. until temperatures were reached at which the Brinell hardness (H<sub>B</sub>/120) had decreased to a value of approximately 350. The diamond pyramid hardness of all the specimens was measured whilst the Brinell hardness (H<sub>B</sub>/120) was measured of specimens in the lower hardness range only, below about 525. The results of the hardness tests are given in Table V and are shown graphically in Figs. 5 and 6. Fig. 5 shows the variation in diamond pyramid hardness with increase in tempering temperature, whilst Fig. 6 shows the variation in Brinell hardness.

Comparison of the "as quenched" hardness with the hardness on tempering at 400° C. gives a measure of the susceptibility to tempering at this temperature, the respective figures being as follows:—

| Steel No. | Silicon Content | Hardness H <sub>D</sub> /30 |           | Difference |
|-----------|-----------------|-----------------------------|-----------|------------|
|           |                 | O.Q.                        | T.400° C. |            |
| 1         | 0.50            | 770                         | 477       | 293        |
| 2         | 1.00            | 802                         | 523       | 279        |
| 3         | 1.32            | 785                         | 567       | 218        |
| 4         | 1.65            | 805                         | 601       | 204        |
| 5         | 1.98            | 775                         | 591       | 184        |
| 6         | 2.32            | 805                         | 632       | 173        |
| 7         | 2.64            | 805                         | 627       | 178        |

These results showed that the susceptibility to tempering of the various steels at 400° C. decreased with increase in silicon content. The slopes of the curves in Fig. 5, however, showed that with increase in tempering temperature above 400° C. the higher silicon steels tend to soften more rapidly than the lower silicon steels.

The hardness of the steels (with the exception of Steel No. 5, 1.98% silicon) increased markedly with increase in silicon content after tempering at any one temperature within the range 450° to 550° C. In order to obtain a

TABLE V.—HARDNESS DETERMINATIONS ON OIL-QUENCHED AND TEMPERED SAMPLES. EFFECT OF VARIATION OF TEMPERING PROCEDURE

| Steel No.                  | 1                  |                     | 2                  |                     | 3                  |                     | 4                  |                     | 5                  |                     | 6                  |                     | 7                  |                     |
|----------------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|
| Silicon %                  | 0.50               |                     | 1.00               |                     | 1.32               |                     | 1.65               |                     | 1.98               |                     | 2.32               |                     | 2.64               |                     |
| Oil-quenching temperature  | 855° C.            |                     | 860° C.            |                     | 865° C.            |                     | 875° C.            |                     | 880° C.            |                     | 850° C.            |                     | 880° C.            |                     |
| Tempering temperature, °C. | H <sub>D</sub> /30 | H <sub>B</sub> /120 | H <sub>D</sub> /30 | H <sub>B</sub> /120 | H <sub>D</sub> /30 | H <sub>B</sub> /120 | H <sub>D</sub> /30 | H <sub>B</sub> /120 | H <sub>D</sub> /30 | H <sub>B</sub> /120 | H <sub>D</sub> /30 | H <sub>B</sub> /120 | H <sub>D</sub> /30 | H <sub>B</sub> /120 |
| 400                        | 477                | —                   | 523                | —                   | 567                | —                   | 601                | —                   | 591                | —                   | 632                | —                   | 637                | —                   |
| 425                        | 457                | —                   | 487                | —                   | 561                | —                   | 613                | —                   | 531                | —                   | 565                | —                   | 573                | —                   |
| 450                        | —                  | —                   | 472                | —                   | 497                | —                   | 523                | —                   | 495                | —                   | 542                | —                   | 548                | —                   |
| 475                        | 424                | 411                 | 451                | 434                 | 473                | 441                 | 495                | —                   | 469                | —                   | 525                | —                   | 512                | —                   |
| 500                        | 406                | 385                 | 421                | 406                 | 442                | —                   | 459                | —                   | 438                | 433                 | 487                | —                   | 493                | —                   |
| 525                        | 392                | 370                 | 396                | 388                 | 403                | 398                 | 432                | 428                 | 416                | 412                 | 452                | 437                 | 438                | —                   |
| 550                        | 364                | 350                 | 373                | 371                 | 392                | 380                 | 407                | 400                 | 390                | 388                 | 425                | 409                 | 446                | 433                 |
| 575                        | —                  | —                   | —                  | —                   | 371                | 363                 | 394                | 389                 | 382                | 379                 | 399                | 397                 | 410                | 407                 |
| 600                        | —                  | —                   | —                  | —                   | —                  | —                   | 368                | 354                 | —                  | —                   | 377                | 375                 | 383                | 380                 |

hardness of 400  $H_D/30$ , a tempering temperature of 500° C. was required in the case of the 0.50% silicon steel and 580° C. in the case of the 2.64% silicon steel. The corresponding temperatures for a Brinell hardness of 400 were 485° C. and 580° C.

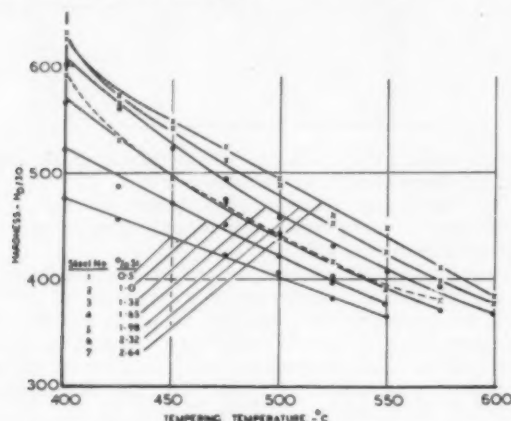


Fig. 5.—Diamond hardness determinations on oil-quenched and tempered specimens showing effect of variation of tempering temperatures.

Steel No. 5 (1.98% silicon) showed exception to the general influence of silicon content, the resistance to tempering of this steel being somewhat similar to that of Steel No. 3 (1.32% silicon) in the temperature range 450° to 550° C.

#### Hardenability Tests

Standard end quench hardenability tests were carried out on all the steels. Each specimen was normalised at temperatures 80° C. above the  $A_{c3}$  point, then end quenched from a temperature 70° C. higher than the  $A_{c3}$  temperature. The results of the tests are shown graphically in Figs. 7 and 8 and calculations of critical diameter for each steel are given in Table VI.

The maximum hardness of the steels varied only from 804 to 831  $H_D/30$  and, in general, increased with increase in silicon content.

The steels were all of the shallow hardening type although they showed distinct differences. The depth hardenability, as judged by ideal critical diameter, showed no appreciable variation over the range 0.5 to 1.32% silicon content and the hardenability

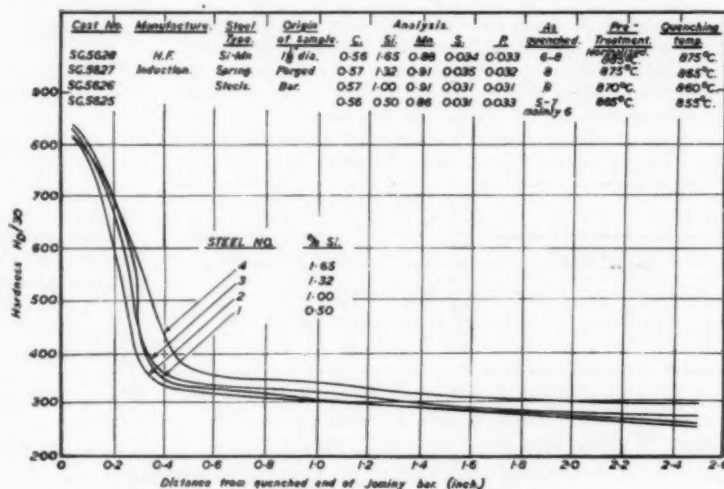


Fig. 7—Jominy hardenability tests.

TABLE VI.—ACTUAL GRAIN SIZE AND CRITICAL DIAMETER OF THE STEELS FROM END-QUENCH HARDENABILITY TESTS.

| Steel No. | Silicon % | Actual Grain Size | Maximum Hardness $H_D/30$ | Distance of Inflection Point from Water-Quenched End Inches | Hardness, $H_D/30$ at Inflection Point | Ideal Critical Diameter Inches | Critical Diameter for Severity of Oil Quench Inches $h = 0.6$ |
|-----------|-----------|-------------------|---------------------------|---|--|--------------------------------|---|
| 1         | 0.5       | 5-7               | 804                       | 0.295   | 450                                    | 2.19                           | 0.65  |
| 2         | 1.0       | Mainly 6          | 810                       | 0.260   | 460                                    | 1.95                           | 0.58  |
| 3         | 1.32      | 8                 | 825                       | 0.290   | 480                                    | 2.08                           | 0.64  |
| 4         | 1.65      | 6-8               | 828                       | 0.345   | 490                                    | 2.31                           | 0.78  |
| 5         | 1.98      | 7-8               | 823                       | 0.300   | 505                                    | 2.12                           | 0.66  |
| 6         | 2.32      | 6                 | 831                       | 0.410   | 480                                    | 2.39                           | 0.97  |
| 7         | 2.64      | 5-7 Mainly 6      | 820                       | 0.595   | 460                                    | 3.24                           | 1.50  |

of the steel containing 1.98% silicon showed little difference from that of the steel containing 1.32% silicon. The hardenability of the three steels containing respectively 1.65, 2.32 and 2.64% silicon was greater than that of the remaining steels and increased progressively with increase in silicon content.

#### Mechanical Tests

Prior to heat-treatment of the steels for tensile and impact tests, the specimens were rough machined to 0.50 in. dia. along the portion constituting the test length. The specimens were oil quenched respectively from temperatures 70° C. above the upper limit of the

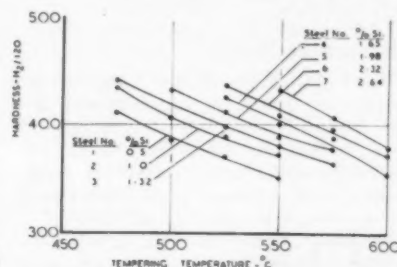


Fig. 6.—Brinell hardness determinations on oil-quenched and tempered specimens showing the effect of variation of tempering temperature.

critical range, then tempered to a hardness of 366/385 Brinell. The results of the tests are given in Table VII.

In spite of the higher silicon steels having been tempered at higher temperatures than the lower silicon steels, in order to obtain a constant maximum stress throughout the series, there was no definite evidence to



TABLE VII.—MECHANICAL PROPERTIES OF  $\frac{1}{2}$  INCH DIAMETER MATERIAL OIL-HARDENED AND TEMPERED TO 360/355 BRINELL.

| Steel No.                            | 1       | 2       | 3       | 4       | 5       | 6       | 7       |
|--------------------------------------|---------|---------|---------|---------|---------|---------|---------|
| Silicon, %                           | 0.50    | 1.00    | 1.32    | 1.63    | 1.98    | 2.32    | 2.64    |
| Treatment:                           |         |         |         |         |         |         |         |
| Hardened                             | 855° C. | 860° C. | 865° C. | 875° C. | 880° C. | 885° C. | 890° C. |
| Tempered                             | 505° C. | 525° C. | 540° C. | 575° C. | 550° C. | 580° C. | 595° C. |
| Maximum Stress, tons per square inch | 82.8    | 82.3    | 82.7    | 81.7    | 82.5    | 82.2    | 80.0    |
| Yield Stress, tons per square inch   | 74.2    | 75.0    | 75.1    | 74.7    | 72.8    | 73.6    | 70.0    |
| Elongation on 2 inches, %            | 14.7    | 16.0    | 16.0    | 18.0    | 15.3    | 17.3    | 20.0    |
| Reduction of Area, %                 | 35.5    | 41.5    | 38.4    | 43.6    | 39.8    | 34.8    | 35.5    |
| Izod Impact Figures, ft. lb.         | 9, 9, 9 | 9, 9, 9 | 8, 8, 8 | 8, 8, 8 | 9, 8, 9 | 3, 6, 7 | 5, 5, 7 |
| Average, ft. lb.                     | 9       | 9       | 8       | 8       | 9       | 5       | 6       |
| Hardness, $H_{120}$                  | 377     | 376     | 384     | 370     | 385     | 378     | 366     |

show improved ductility or toughness in these steels. The steel of lowest silicon content had the lowest elongation and the steel of highest silicon content had the highest elongation, but the elongation figures of the remaining steels bore no relation to the silicon content. The reduction in area values also showed no relation to the silicon content. The notch impact toughness, however, tended to decrease when the silicon content was greater than 2.0%, although the tempering temperature of these steels was appreciably higher than that of the remainder. Apart from this latter feature of lower toughness, there was little to choose between the various steels as regards mechanical properties.

### Fatigue Tests

Specimens for rotary fatigue tests were rough machined to 0.50 in. dia. along the test length, then subjected to the same heat-treatment as the tensile and impact tests. The specimens were then ground and polished longitudinally for one set of tests and circumferentially notched for a second set of tests, the form of

notch corresponding to that of a  $\frac{3}{8}$  in. Whitworth thread. The specimens were tested in a Wöhler rotating cantilever machine, with single point loading at a speed of 2,840 revolutions per minute, the basis of the limiting stress being the highest range of stress which the material would carry without failure for ten million reversals.

The results of these tests are shown graphically in Figs. 9 to 15, and summarised in Fig. 16 and Table VIII.

The limiting fatigue stress values of un-notched specimens tended to decrease with increase in silicon content from a value of  $\pm 47.0$  tons per sq. in. for the steel containing 0.475% silicon, to  $\pm 42.5$  tons per sq. in. for the steel containing 2.50% silicon. The values for the ratio limiting fatigue stress/maximum stress (fatigue ratio) showed a smaller variation from 0.57 to 0.52, the higher silicon steels having the lower ratio.

The presence of the notch reduced the limiting fatigue stress from a figure of about  $\pm 45.0$  tons per sq. in. to about  $\pm 19.0$  tons per sq. in. The limiting fatigue stress, in the presence of the notch, showed no consistent variation with increase in silicon content, the values ranging from  $\pm 18.2$  to  $\pm 21.0$  tons per sq. in.

The notch sensitivity\* of the steel of lowest silicon content (0.475%) was highest at a figure of 0.61, that of the remaining steels varying from 0.55 to 0.58 and showing no relation to the silicon content.

### Summary.

The following summarises the results of tests carried out to determine the susceptibility to decarburisation, hardness on quenching, response to tempering hardenability and mechanical and fatigue properties of a series of silico-manganese steels varying in silicon content from 0.50 to 2.64%.

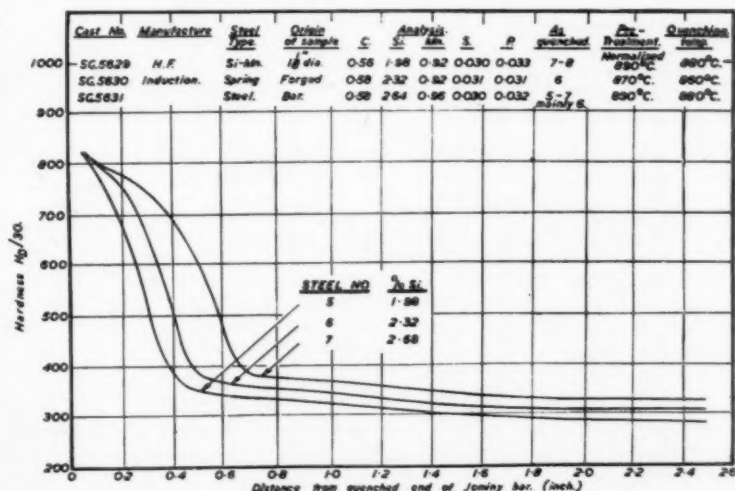


Fig. 8.—Jominy hardenability tests.

TABLE VIII.—WÖHLER ROTATING CANTILEVER FATIGUE TESTS.

| Steel No.   | 8     | 9    | 10    | 11   | 12   | 6    | 13   |
|---|-------|------|-------|------|------|------|------|
| Silicon, %  | 0.475 | 1.02 | 1.32  | 1.63 | 1.98 | 2.32 | 2.60 |
| Type of Specimen                                      | P     | N    | P     | N    | P    | N    | P    |
| Maximum Stress (MS), tons per sq. in.                 | 82.8  | 82.3 | 82.7  | 81.7 | 82.5 | 82.2 | 80.0 |
| Limiting Fatigue Stress (LFS), $\pm$ tons per sq. in. | 47.0  | 47.0 | 46.25 | 46.5 | 43.0 | 44.0 | 42.5 |
| Fatigue Ratio, $\frac{LFS}{MS}$                       | 0.57  | 0.57 | 0.56  | 0.57 | 0.52 | 0.54 | 0.53 |
| Notch Sensitivity, $\frac{P-N}{P}$                    | 0.61  | 0.56 | 0.58  | 0.55 | 0.58 | 0.56 | 0.57 |

P = Plain Specimen .. 0.3 inch diameter.  
 N = Notched Specimen {  $\frac{3}{8}$  inch Whitworth form of thread.  
 { 0.335 inch diameter at top of notch.  
 { 0.295 inch diameter at bottom of notch.

\* Notch sensitivity =  $\frac{LFS \text{ of plain specimen} - LFS \text{ of notched specimen}}{LFS \text{ of plain specimen}}$

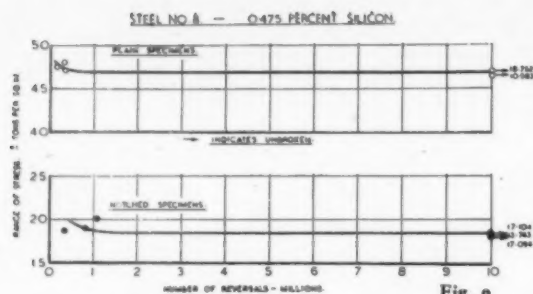


Fig. 9

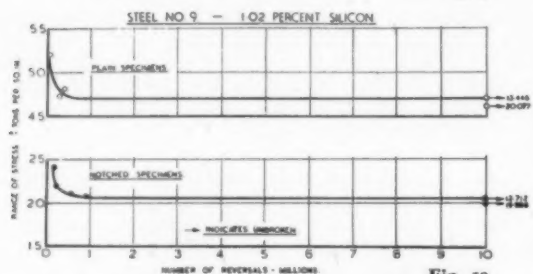


Fig. 10

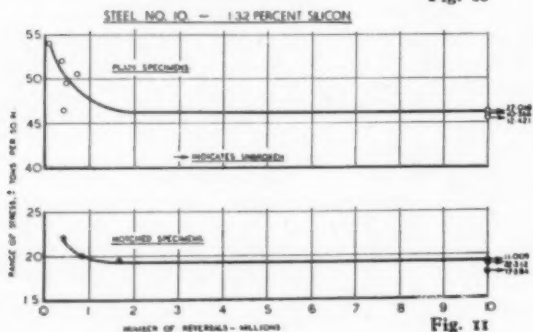


Fig. 11

Figs. 9, 10, and 11.—Wohler rotating cantilever fatigue tests.

- (1) The depth of decarburisation in samples heated in an atmosphere consisting of 16% carbon dioxide, 3.5% oxygen and 80.5% nitrogen at a temperature of 1,000° C., showed a marked decrease with increase in silicon content above 1.65% for heating times of 15 and 30 min.
- (2) The steels containing up to 1.98% silicon showed appreciable decarburisation with only 5 min. heating at a temperature of 1,000° C., whilst the steel containing 2.32% silicon required more than 5 min. and the steel containing 2.64% more than 15 min. heating before definite decarburisation occurred.
- (3) The depth of decarburisation in samples heated in an atmosphere consisting of 7% carbon dioxide, 12.0% oxygen and 81.0% nitrogen at a temperature of 1,150° C., showed no relation to the silicon content.
- (4) The optimum hardness values of the various steels were within the range 769 to 814  $H_p/30$  and were obtained by oil quenching from a temperature of 850° C. or 875° C. There was a definite tendency for the optimum hardness to increase with increase in silicon content.

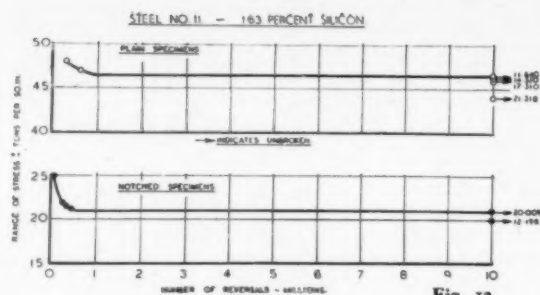


Fig. 12

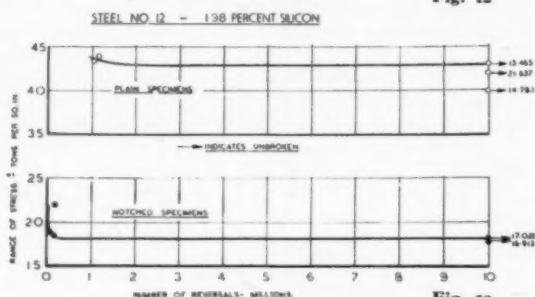


Fig. 13

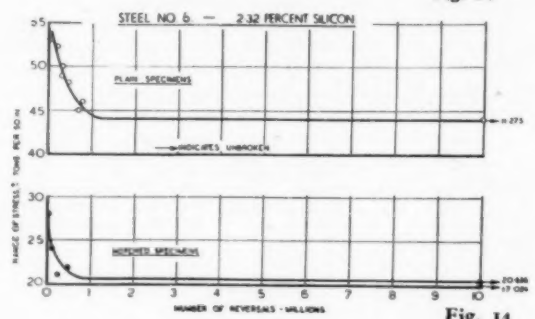


Fig. 14

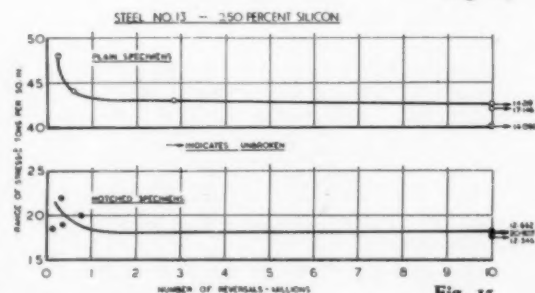


Fig. 15

Figs. 12, 13, 14, and 15.—Wohler rotating cantilever fatigue tests.

- (5) Increase in silicon content resulted in a marked decrease in the response to tempering. The temperature difference on tempering for equal Brinell hardness (400) in the case of the steels containing 0.5 and 2.64% silicon was 90° C., the higher silicon steel requiring the higher temperature.
- (6) The steels containing up to 1.98% silicon showed no pronounced variation in hardenability, but increase in silicon content to 2.32 and 2.64% resulted in progressive increases in hardenability.

- (7) In quenching, tempering and hardenability tests, Steel No. 5 (1.98% silicon) showed exceptional results with respect to the remaining steels and had similar properties to Steel No. 3 containing 1.32% silicon.

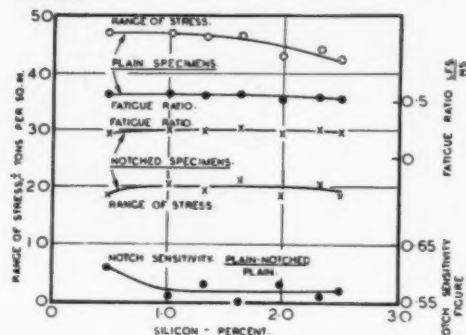


Fig. 16.—Wohler rotating cantilever fatigue tests.

- (8) In spite of the higher tempering temperatures required in the case of the higher silicon steels for a specified hardness, these steels showed no improvement in mechanical properties over the lower silicon steels when tempered to a hardness of 380 H<sub>RC</sub>/120, the former being actually inferior in notch bar impact value.
- (9) The fatigue ratio tended to decrease slightly in the range 0.57 to 0.52 with increase in silicon content.

- (10) The notch sensitivity of the steel containing 0.50% silicon was 0.61, that of the remaining steels was within the narrow range of 0.55 to 0.58.

### Conclusions

The foregoing tests on an experimental series of silicon-manganese spring steels showed that by increasing the silicon content above 1.50% a definite advantage is obtained by an increased resistance to decarburisation on heating at 1,000° C.

Although increase in silicon content from 0.5 to 2.64% produced a progressive increase in resistance to tempering, resulting in higher tempering temperatures for equal hardness, no corresponding improvement in ductility was obtained with the higher silicon steels when all the steels were treated to a uniform tensile strength. Notch impact toughness and fatigue ratio tended to be somewhat inferior in the steels containing more than 2.0% silicon.

The present range of 1.5 to 2.0% silicon as specified in B.S.S. 970 (1947) for En.45 and 45A, is probably an optimum since decrease in silicon below the lower limit increases the susceptibility to decarburisation, whilst increase in silicon above the maximum of the range is liable to produce inferior notch impact toughness and fatigue strength.

### Acknowledgments

The authors desire to express their thanks to Mr. F. H. Saniter, Director of Research, for permission to publish this paper.

## Recent Progress in Corrosion-Resisting Nickel-Base Alloy Castings

By M. M. Hallett, M.Sc., F.I.M.

Chief Metallurgist, The Sheepbridge Stokes Centrifugal Castings Co., Ltd.

*For many years certain nickel-base alloys have been used in the U.S.A. to withstand very severe corrosive conditions. In the past, the demands for such materials in this country have been met by imports from America, but the changing economic conditions have stimulated the development of production facilities in this country. The extent to which success has been achieved is illustrated by reference to a recently completed contract for castings in these materials.*

IN the United States of America nickel-base alloys, known as Hastelloy\* A, B, C, and D, have been widely used for many years to withstand abnormally severe corrosion conditions. These alloys are based either on the nickel-molybdenum series, sometimes with additions of chromium, or on the nickel-silicon series. The range of available materials enables most corrosive conditions to be withstood. Thus, an alloy of nickel with about 30% of molybdenum has an excellent resistance to hydrochloric acid of all concentrations at all temperatures, and, in addition, has an outstandingly good resistance to sulphuric acid under all conditions except those involving contact with boiling strong acid. This latter condition is best withstood by an alloy of nickel with about 10% of silicon. An alloy of general usefulness is obtained at a composition of 18% molybdenum with 15% chromium, which, in addition to withstanding the

attack of dilute sulphuric and hydrochloric acids over a wide range of temperature, also possesses good resistance to nitric acid and to corrosive metallic salts with high concentrations of chloride ions (such as ferric chloride and cupric chloride) and to free chlorine. The mechanical properties of the nickel-molybdenum alloys are good, and they are machinable without too much difficulty, but the nickel-silicon alloys are more brittle and are generally regarded as unmachinable. Their mechanical properties are, however, greatly superior to those of 14% silicon iron, which also has a good resistance to corrosion.

In the past, most of the demands for these materials in this country have been met by importation from America, but the changing economic situation has stimulated efforts to develop production facilities on this side of the Atlantic. A useful start has been made, so far as the production of castings is concerned, and two or

\* Registered trade mark of Haynes Stellite Company.

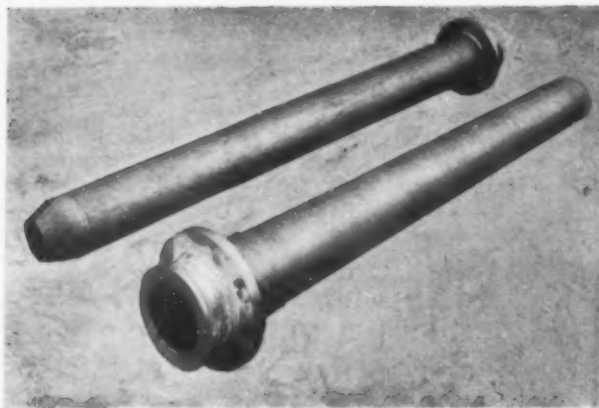


Fig. 1.—Corrosist "D" heater tubes for sulphuric acid concentration.

three foundries have made considerable progress towards this goal. Of these, the Sheepbridge Stokes Centrifugal Castings Co., Ltd., has introduced a family of alloys, under the trade name of Corrosist, the individual members being referred to as "B," "C," or "D." They are regarded as equivalent to the corresponding grades of Hastelloy. Considerably the largest contract in this field has recently been completed by the Sheepbridge Stokes Company at their Sutton-in-Ashfield works, and a description of this job may be of interest in revealing the satisfactory position which now exists in this country.

The contract was from Simon-Carves, Ltd., who were erecting a large plant for the vacuum concentration of weak waste sulphuric acid up to 93% strength under fume-free conditions. The contract called for the use of the nickel-silicon alloy, Corrosist "D," since this grade has an outstandingly good resistance to boiling strong sulphuric acid, and comprised heater tube castings, valve assemblies and inlet pipes.

Of these, the major item was the heater tubes, which numbered nearly 100. The finished casting weighed 315 lb. and consisted of a cylindrical tube slightly over 6 ft. long and 7 in. outside diameter, with a wall thickness  $\frac{3}{8}$  in. The tube was closed at one end and was cast with a flange and spigot portion carrying a coned joint face at the other end. This will be made clear by reference to Fig. 1, which shows two tubes. The tube was required to be straight to within  $\frac{1}{4}$  in. The tolerance on wall thickness was  $\pm \frac{1}{16}$  in. (as cast) and the finished machined tube was required to withstand a pressure test in which it was filled with kerosene and held at 400 lb./sq. in. for 30 minutes without showing any signs of leakage. It will be clear to the foundryman that this is a formidable specification for any material, and was particularly stringent when applied to specialised material of this type. For example, the core had to be entirely supported from the open end of the casting, since chaplets could not be tolerated, and the closed end had to be cast solid without welding.

The valve assemblies included valve bodies and plugs over a range of sizes and in weights varying roughly from 28–140 lb. The test conditions on these were less stringent, but the same standard was required as laid down in B.S. 1333 for silicon iron castings, and a 50-lb. kerosene pressure test was applied to the valve body castings, and to the finished assembly, to check leakage

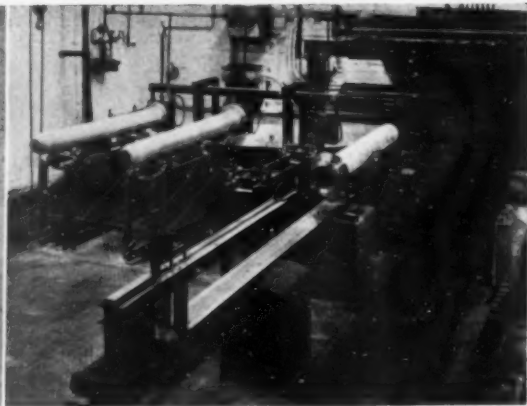


Fig. 2.—Testing of Corrosist "D" heater tubes.

across the seat. The valve plug was of some interest, since it was cast around a mild-steel spindle. Several plugs were broken open for inspection, and a good joint, entirely free from porosity, was found between the spindle and the plug in each case.

Other castings of somewhat unusual types included some extremely long combined valve spindles and plugs, in the longest of which the spindle was 15 ft. 9 in. long and  $1\frac{1}{4}$  in. dia. The principal problem in this type of casting was that of contraction leading to hot tearing. It need only be pointed out that the linear contraction on the spindle was 4 in., in order to appreciate the difficulties involved. The inlet pipes, which weighed 420 lb. as finished, were 9 ft. 10 in. long, 6 in. bore and  $\frac{3}{8}$  in. wall thickness. They were provided at one end with a standard cone end and flange. In all, nearly 200 castings were produced with a total finished weight of over 17 tons.

The production of these castings calls for a high degree of technical control and first-class foundry equipment. The castings were produced from high-frequency electric furnace melts, paying particular attention to control of composition and melting and pouring temperatures. In addition to routine analysis, regular corrosion tests were carried out to ensure that the material was capable of withstanding the service conditions. A contract of this magnitude also called for the provision of much special equipment. All the pattern equipment and moulding equipment was made specially for the job and treated on precision machining lines, working to much finer tolerances than normal in foundry equipment of this type. Only by continuous attention to all such details could the job be successfully completed.

The inspection procedure also justified special equipment. Particularly in the earlier stages of development, many of the castings were subjected to radiographic examination, and all scrap tubes were broken up and the causes of the defects were carefully analysed before making further castings. The layout of the inspection equipment for the pressure tests and dimensional checks on the tubes is illustrated in Fig. 2. This shows three stations for carrying out pressure tests, on two of which tubes are in position. On the right of the photograph can be seen the equipment built for the measurement of wall thickness at any desired point along the length of the casting.



One point illustrated by Figs. 1 and 2 is the good finish obtained on the machined surfaces. This grade of material is normally regarded as unmachinable. It is certainly extremely difficult, having a hardness between 550 and 600 D.P.H., but it has been found that, with suitable equipment and a special technique, facing and turning operations are practicable. The finished faces on these tubes were prepared by turning and not by grinding.

Although this particular job was outstanding by reason of its size and complexity, many other castings have been made in the "D" grade of Corrosist and in the nickel-molybdenum alloys, Corrosist "B" and Corrosist "C." To turn to the other end of the scale, mention may be made of small float castings produced in

Corrosist "B" for the British Diesel Oil & Petrol Co., Ltd., for use in flow-meters handling sulphuric acid. This application is of some interest, since, although the corrosive conditions are not particularly severe, it is essential that the casting be entirely free from corrosion, as any loss would affect the metering action of the apparatus.

#### Acknowledgment

We are indebted to the author and to the Mond Nickel Co., Ltd. for permission to reproduce this article which appeared in *The Nickel Bulletin* for November, 1948, acknowledgment is also made to Broadley & Foster Ltd., for their co-operation in the evolution of the moulding technique.

# The Fracture of Solids

## II—The Fracture of Glass

By Professor H. Moore, D.Sc., A.R.C.S., F.Inst.P.

*Department of Glass Technology, Sheffield University*

*The second paper\* of the conference on The Fracture of Solids organised by the British Rheologists' Club was given by Professor Moore who discussed the fracture of glass. In his introductory remarks he pointed out that the phenomena of fracture should be explainable in terms of structure, but that a theory of fracture could not be based on a study of fracture alone. Vitreous silica consists of  $\text{SiO}_4$  tetrahedra linked by the oxygens at the corners, each tetrahedron having four linkages at  $120^\circ$  to each other. In silicate glasses the introduction of alkali, such as  $\text{Na}_2\text{O}$ , breaks these linkages, but divalent oxides, such as lime ( $\text{CaO}$ ) can provide bridges between tetrahedra which have become temporarily separated. On the molecular scale the structure is irregular, but on any larger scale it is isotropic, giving rise to the familiar conchoidal type of fracture. . . . As with metals the strength calculated from the structure is many thousand times greater than the observed strength. Fine freshly drawn glass fibres are, however, many hundred times stronger than massive glass, but the strength diminishes rapidly in moist air.*

IT is no easy matter to put together a paper on the fracture of glass. This is not because there is any lack of published material, but rather because there is too much available. Unfortunately most of it is purely factual or observational information giving very little on which fundamental ideas can be based.

We all know that glass has a conchoidal fracture, and we can ascribe this to the isotropic structure of glass. But there may be many types of isotropic structure, so we are not really much advanced by that. Moreover, quartz has a conchoidal fracture, and so has chilled high-carbon steel, neither of which can be regarded as isotropic. Quartz owes its conchoidal fracture to the tetrahedral  $\text{SiO}_4$  units from which it is built up, and to their being linked in identical ways along four directions making angles of  $120^\circ$  with each other. Chilled high-carbon steel owes its conchoidal fracture to the minuteness of its constituent crystals and to their close interlocking. The structure of a material may thus enable us to explain the way in which fracture occurs and the appearance which the fractured surface will present, but the appearance of a fractured surface will not necessarily give us any conclusive fundamental information about the nature of the material.

I could, of course, refer to many papers dealing with the appearances of fracture surfaces when glass is broken in different ways. It is possible, for example, to identify

the direction in which fracture has proceeded along a crack or diamond cut by observation of the curved ridges or "hackle marks" in the fracture surfaces. Many papers have been written on this matter and on the shape of the central "cone" which can be knocked out of a piece of glass by normal impact of a hard body. Such information has, on occasion, been useful when the police have needed help in investigating how a window was broken and from which side. Some of the authors, however, have been rather over-venturesome in my opinion, for some of them have put forward suggestions of glass-structure, based on these observations, which were not always entirely credible.

I propose, therefore, to start from what we know of glass structure, and to build up ideas about fracture from that, mentioning experimental observations where they appear to be relevant. The structure of vitreous silica is built up of tetrahedral units, each having a silicon atom at its centre with four atoms of oxygen round it at the corners of the tetrahedron. These tetrahedra are all bonded to adjoining tetrahedra, or should be, by the oxygen atoms at the corners, each oxygen atom being shared by two tetrahedra. The attachment is by corners only, not by edges, no two tetrahedra sharing more than one oxygen atom. Quartz, cristobalite and tridymite are also built up in this way, but in these crystalline forms of silica the structure is regular, in "rings" of six tetrahedra, whereas in vitreous silica the grouping is irregular, the number of

\* The first paper on "The Fracture of Glass" given by Dr. C. F. Tipper was published in the January issue pp. 133-137.

tetrahedra in individual rings being variable, though on the average the number is about six.

In an ordinary silicate glass conditions are a little more complicated. The usual soda-lime-silica glasses contain alkali ( $\text{Na}_2\text{O}$ ) and lime ( $\text{CaO}$ ) in proportions which can be represented roughly as between  $1.2 \text{ Na}_2\text{O} \cdot \text{CaO} \cdot 6\text{SiO}_2$ , and  $1.4 \text{ Na}_2\text{O} \cdot \text{CaO} \cdot 6.5\text{SiO}_2$ , though these are in no sense definite limits. When a mixture of sand, limestone, and sodium carbonate is heated, the bonds between adjacent  $\text{SiO}_4$  tetrahedra will here and there become temporarily broken due to thermal vibrations, and if a soda molecule is nearby it may link on to the open ends and so prevent the tetrahedra from joining together again. In effect the  $\equiv\text{Si-O-Si}\equiv$  linkage is broken temporarily, giving  $\equiv\text{Si-O-}$  and  $-\text{Si}\equiv$ , and this condition is then altered to  $\equiv\text{Si-O-Na}$  and  $\text{Na-O-Si}\equiv$  by the introduction of the soda molecule. In this state of affairs the sodium atom is fully satisfied and the structure remains permanently disrupted so long as the sodium atoms retain their positions.

A lime molecule behaves in a similar manner in the sense that it prevents the  $\text{SiO}_4$  tetrahedra from becoming bonded directly together again, but, as calcium is di-valent, there seems to be no reason why it should not link itself into the system so as to re-establish continuity through a bridge which may be represented as  $\equiv\text{Si-O-Ca-O-Si}\equiv$ . In that case, the structure will be more open than before, and weaker in consequence, but it will not be disrupted, as happens when an alkali molecule inserts itself into the silica structure. There is evidence suggesting that covalent bonds may be formed, linking some of the alkali atoms with neighbouring oxygen atoms and thus reducing the weakening effect which would be expected to result from the complete disruption already referred to.

Now if we start from this picture of the structure of an ordinary soda-lime-silica glass, we can deduce some of the properties of such a glass in a qualitative manner, and may be able eventually to make some quantitative deductions.

In the first place, a glass should be equally strong in all directions, a deduction which, so far as average values are concerned, is in accordance with observation.

Owing to the bonding of most of the tetrahedra being identical in four directions at  $120^\circ$  to each other, also, the structure will be rigid, unlike the many flexible organic materials with long chain molecules attached at comparatively few points by side linkages. When a local rupture occurs there will be little opportunity for readjustment of the grouping or bonding in the immediate vicinity of the rupture — there are no slip planes in glass — and complete fracture will occur as soon as, or almost as soon as local rupture is caused, i.e., glass must be brittle, with no appreciable difference between yield stress and breaking stress.

It is possible on this knowledge of glass structure to calculate an upper limit for the rupture strength of glass, since this would correspond fairly closely with the calculated value for the strength of quartz, or, perhaps, tridymite. The number of Si-O bonds across unit-area of cross-section, multiplied by the strength of a single bond, would give the value of this upper limit. I believe that this has been done, and that the value is many thousands of times greater than the observed values even for quartz, so it does not get us very far.

The mechanical strength of any material, is of course, determined by any localised flaw or imperfection of structure, so we may expect even quartz to be far weaker

than theory would indicate. Such weakness may arise from imperfections either in the interior or on the surface, and, as a matter of fact, it appears to be mainly caused by surface condition. In flat glass, for example, the surface layers have an average strength of 4 to 6 kgm./sq. mm. if the surface has a "fire finish", but only about 2 to 3 kgm./sq. mm. if the surface has been ground and polished. In the interior of a "toughened" glass, however, it is possible to produce tensions of 10 to 12 kgm./sq. mm. without fracture occurring, and these values could probably be very greatly exceeded if special care were taken to ensure that the glass was free from minute local faults.

In fine drawn fibres of glass the tensile strength immediately after drawing may be of the order of 250 to 300 kgm./sq. mm., though exposure to moist air for even a few seconds causes a marked reduction in strength under test.

In the breaking of glass, also, there is a marked time-effect. A glass may momentarily be able to carry a load some three or four times greater than the load needed to break the glass if maintained for many hours.

Tests carried out at different temperatures do not indicate that the tensile strength diminishes as the temperature rises; in fact, some observers have recorded an increase in tensile strength at high temperatures though others have not observed any significant difference.

It is to be remarked in connection with all mechanical tests of glass that the spread of the results is very great, covering ranges such as 2-8 kgm./sq. mm. on test specimens cut from the same sheet or rod, and prepared in identical ways. Any tests must thus be made on a minimum of 50 specimens if a single reliable value is to be obtained, and preferably the number *per test* should be 250 or even 500.

To account for the "surface" weakness, Griffith has put forward a "surface flaw" theory which goes far to explain the kinds of effects observed and the great variation among the results of tests on what would be regarded as identical specimens. If this flaw theory is extended by a recognition of the chemical effects which may and do occur in the surfaces of the flaws, it explains most of the observations. It is possible, also, to put forward theoretical views of a quantitative nature with the object of calculating conditions in which a flaw will tend to grow and lead to "delayed" fracture. Such calculations, however, involve assumptions concerning the surface energy of the glass as the area of the sides of the flaw increases, and on this we have very little definite knowledge. The nature of a freshly fractured glass surface changes extremely rapidly on exposure to moist air, and probably also on exposure to dry air though not to the same extent. Any calculations involving surface energy, such as the calculations of the energy changes occurring as fracture proceeds, should be based on the surface energy at the moment of fracture; if they are based on the surface energy of an "aged" surface, even if the "ageing" does not exceed a few seconds, they will certainly be in error and the error may be large.

The question of fatigue of glass is one on which I must say a little, since it is a matter about which enquiry is often made. I do not wish to trespass on anyone else's ground by giving my views on metals, but since the term "fatigue" is used in a special application in connection with fracture of metal I must use it in the same way when I am dealing with glass.

As I understand it, fatigue of metals is due to progressive breakdown of the crystals followed by eventual

separation at the crystal boundaries. Ageing-cracks, on the other hand, are due to the very slow growth of crystals in metals which have been considerably work-hardened (i.e., have had their crystals broken down and distorted) and have not then been sufficiently annealed.

In glass we have no crystals nor crystal aggregates. The structure of a mass of glass is continuous throughout, though there are local irregularities in that structure. There may be large molecular groupings in which the internal linkages are more or less complete. On the boundaries of these groupings there may be a somewhat larger proportion of alkali atoms causing "stopped" ends. But between two such groupings there will be many direct oxygen linkages providing continuity, and there are no definite structural discontinuities at the interfaces of such groups as there are at the interfaces between crystals in metals.

When glass is subjected to successive reversals of stress it flexes or twists like a metal, but even after many millions of such reversals there is no evidence of

weakening. Glass, in fact, shows no evidence of fatigue in the ordinary sense of the word as it is applied to metals. Exposure of a glass to a moist atmosphere causes changes in the nature of the surface glass; it also causes changes in the surfaces of any minute flaws penetrating below the surface proper. The surface changes cause a weakening of the surface layers, and one of the effects produced by absorption of moisture is to fill up the flaws in the surface so that they tend to be wedged apart and to penetrate still further into the glass. This causes a type of fatigue which is analogous to corrosion fatigue of metals, causing the delayed type of fracture under load already referred to, but of fatigue in the ordinary sense there is no sign in glass.

To sum up, our knowledge of glass fracture is like Sam Weller's knowledge of London, "extensive and peculiar". It is largely factual, and in parts we can explain it from our knowledge of glass structure. But we need to know much more about glass and glass structure before we can explain all the phenomena of glass fracture.

## Plating and Pickling Beryllium-Copper Components

By E. E. Halls

*The oxide films formed during the heat-treatment of beryllium copper are rather more difficult to remove by pickling than are those on most other copper alloys. Details of a suitable pickling procedure are given in this article. The author also discusses the procedure for electrodepositing the various metals on beryllium copper for such purposes as corrosion protection, assisting soldering and increasing high-frequency conductivity.*

**P**RIOR to the commercial introduction of the beryllium-copper alloys, there was no alternative to steel for many purposes where high mechanical properties were required. Susceptibility to corrosion and to corrosion-fatigue had to be faced and to provide protective coatings was not always easy or even possible, especially on very small and delicate components. In the case of hardened steels, too, the possibility of hydrogen embrittlement due to acid pickling and electroplating processes was always a positive hazard. In consequence, the introduction of a material of superior corrosion resistance and electrical conductivity, which could be readily fabricated in the soft, quenched condition and

finally hardened in component form, by a low-temperature treatment, proved of immense importance to the lighter engineering industries in general and to the electrical industry in particular. Its special suitability for springs, whether of the coil, flat or complex type, diaphragms and parts which have to withstand corrosion, erosion or wear, has established it firmly as an indispensable material in all classes of precision instruments. All forms of mechanically and electrically operating apparatus, such as clocks, meters, gauges, telephone, telegraph, teleprinter, radio, remote control and automatic equipment take advantage of the special properties of this material in one application or another.

TABLE 1.—BEHAVIOUR OF ROLLED-SHEET SPECIMENS OF COPPER AND COPPER-RICH ALLOYS UNDER SALT-SPRAY EXPOSURE

| Sample No.      | Metal                             | Appearance after period of salt-spray test in days:— |  |  |  |
|-----------------|-----------------------------------|--|--|--|--|
|                 |                                   | 1  | 7  | 14   | 28   |
| Sample No. 1 .. | Copper..                          | Very slight greenish-yellow tarnish.                 | Slight superficial greenish corrosion points or areas. | Slight green corrosion. General.   | Green corrosion heavier and general.                                   |
| " 2 ..          | $\alpha$ - $\beta$ Brass.         | Lightly stained.                                     | Ditto.   | Preferential corrosion of zinc to slight general white deposit on a background of copper-coloured patches. | Corrosion heavier, but still preferential, with marked white deposits. |
| " 3 ..          | Phosphor Bronze (5% Tin).         | Very slight greenish-yellow tarnish.                 | Ditto.   | Slight green corrosion. General.   | General green corrosion, heavier.                                      |
| " 4 ..          | Aluminium Bronze (10% Aluminium)  | Lightly stained.                                     | Ditto.   | Areas of slight green corrosion.   | Green corrosion now general and rather heavier.                        |
| " 5 ..          | Nickel Silver (18% Nickel.)       | Unaffected.  | Unaffected.  | Unchanged.   | Very slight green corrosion, but not general.                          |
| " 6 ..          | Beryllium Copper, (2% Beryllium.) | Lightly stained.                                     | Slight superficial greenish corrosion points or areas. | Very slight green corrosion.   | Green corrosion now general and rather heavier.                        |



TABLE II.—BEHAVIOUR OF ROLLED-SHEET SPECIMENS OF COPPER AND COPPER-RICH ALLOYS UNDER CYCLIC HUMIDITY CONDITIONS

| Sample No. 1 | Metal                             | Appearance after period of humidity test in days :— |                                |                  |
|--------------|-----------------------------------|---|--------------------------------|------------------|
|              |                                   | 1   | 10                             | 50               |
| 1            | Copper.                           | Unaffected  | Slight tarnish discolouration. | No marked change |
| 2            | $\alpha$ - $\beta$ Brass.         | Ditto   | Unaffected                     | Ditto            |
| 3            | Phosphor Bronze (5% Tin).         | Ditto   | Ditto                          | Ditto            |
| 4            | Aluminium Bronze (10% Aluminium). | Ditto   | Ditto                          | Ditto            |
| 5            | Nickel Silver (18% Nickel).       | Ditto   | Ditto                          | Ditto            |
| 6            | Beryllium Copper (2% Beryllium).  | Ditto   | Slight tarnish discolouration. | Ditto            |

### Corrosion Resistance

The data presented in Tables I to IV illustrate the comparative corrosion resistances of the principal copper-rich alloys under severe and relatively moderate conditions. Table I refers to salt-spray exposure in which specimens were subjected to the mist from 20% salt solution, atomised with compressed air at room temperature. The daily test cycle comprised 8 hours with the spray operating, 15 hours in the mist-laden chamber, and 1 hour for removal of specimens, washing them in running water, and drying on a soft cloth for examination. Under the particular conditions obtaining in the test as applied, it will be seen from the details in Table I, that the following facts emerge :—

- All the metals examined resist attack very well and, with the possible exception of nickel silver, their behaviour is fairly closely the same. The performance of the nickel silver is exceptionally good.
- Nickel silver and aluminium bronze are the most resistant to the conditions, with beryllium copper next in order of merit.
- Brass proved to be a little inferior to copper and phosphor bronze.

The tests demonstrate that beryllium copper is susceptible to "verde gris" corrosion, when exposed to salt atmospheres, in a similar manner to the attack on other copper-rich metals.

Table II deals with the same metals, chemically cleaned and exposed to a mild humidity test. In this, the daily cycle comprised 8 hours under warm dry conditions averaging 55° C. and 65% humidity, and 16 hours in dampness obtained by cooling to atmospheric temperature with rise in humidity to 100% and moisture condensation upon the specimens. The high-copper metals—namely, copper itself and beryllium copper, tarnished somewhat, but generally virtually no deterioration occurred.

Table III covers the same series of specimens severely handled after chemical cleaning in order to finger mark them, and again submitted to the humidity test. It will be seen that the finger marking quickly resulted in

superficial tarnishing except on aluminium bronze and nickel silver, and that these two metals were outstandingly superior at the end of the test. In fact, the aluminium bronze was practically unaffected. All the other samples behaved closely the same—viz., exhibiting definite surface deterioration, not serious but positively established.

The humidity tests establish that under normal conditions of handling and atmospheric variations, similar superficial deterioration occurs in beryllium copper as in the other coppers and copper-rich alloys.

Table IV summarises the analytical and hardness characteristics of the samples tested to show that there was nothing unusual in any of them.

The tests described are, of course, purely comparative and empirical, and cover only the corroding influences mentioned. Many others, of course, are likely to be experienced, in factories and offices, in refineries and mines, and in hotel kitchens, etc. Hence, the results obtained should not be generalised to cover untested fields.

Under a wide variety of service conditions in which fluctuations of temperature and humidity from arctic to tropical, and the contamination of industrial and marine atmospheres are encountered, beryllium-copper exhibits very good resistance to corrosion. In comparison with the spring steels, it is virtually non-corrodible. Nevertheless, under severe conditions of excessively acid atmospheres, such as those entailing high concentrations of sulphurous acid or hydrogen sulphide, some deterioration must occur. Quite apart from safeguarding components from these special conditions, however, electroplated finishes are required for specific reasons. A coating may be required merely to prevent deterioration in appearance such as would result from normal gradual tarnishing. It may be required to ensure permanence of good "dry" electrical contact by providing for a low-contact resistance, particularly as many frail spring clips are used at very light pressures, or for high-frequency electrical conductivity.

Soldering may be involved, and this is required to be performed without upsetting any prior hardening : a

TABLE III.—BEHAVIOUR OF ROLLED SHEET SPECIMENS OF COPPER AND COPPER RICH-ALLOYS, CHEMICALLY CLEANED AND SEVERELY HANDLED, UNDER CYCLIC HUMIDITY CONDITIONS

| Sample No. 1 | Metal                             | Appearance after period of humidity test in days :— |  |   |
|--------------|-----------------------------------|---|--|---|
|              |                                   | 1   | 10   | 50  |
| 1            | Copper.                           | Slightly tarnished.                                 | More tarnished and slight corrosion pattern of finger marking. | Deterioration a little more marked.                               |
| 2            | $\alpha$ - $\beta$ Brass.         | Unaffected.   | Ditto  | Ditto   |
| 3            | Phosphor Bronze (5% Tin).         | Slightly tarnished.                                 | Ditto  | Ditto   |
| 4            | Aluminium Bronze (10% Aluminium). | Unaffected.   | Unaffected.  | Almost unaffected.  |
| 5            | Nickel Silver (18% Nickel).       | Unaffected.   | Unaffected.  | Very slight tarnishing with heavier marking due to finger prints. |
| 6            | Beryllium Copper (2% Beryllium).  | Slightly tarnished.                                 | More tarnished and slight corrosion pattern of finger marking. | Deterioration a little more marked.                               |



TABLE IV.—LABORATORY CHARACTERISTICS OF THE METALS REFERRED TO IN TABLES Nos. I-III

| Sample No. . . . .       | 1         | 2         | 3               | 4                | 5             | 6                |
|--------------------------|-----------|-----------|-----------------|------------------|---------------|------------------|
| Metal . . . . .          | Copper    | Brass     | Phosphor Bronze | Aluminium Bronze | Nickel Silver | Beryllium Copper |
| Composition per cent.    |           |           |                 |                  |               |                  |
| Copper . . . . .         | Remainder | 64.7      | Remainder       | Remainder        | 57.8          | 97.6             |
| Oxygen . . . . .         | 0.031     | —         | —               | —                | —             | —                |
| Arsenic . . . . .        | 0.006     | —         | —               | —                | —             | —                |
| Zinc . . . . .           | Traces    | Remainder | —               | 0.40             | Remainder     | —                |
| Tin . . . . .            | Traces    | Nil       | 5.0             | Traces           | Nil           | —                |
| Aluminium . . . . .      | Traces    | Nil       | —               | 10.54            | —             | —                |
| Nickel . . . . .         | Traces    | Nil       | —               | 0.07             | 17.5          | —                |
| Beryllium . . . . .      | —         | —         | —               | —                | —             | 2.05             |
| Cobalt . . . . .         | —         | —         | —               | —                | —             | 0.24             |
| Silicon . . . . .        | Traces    | —         | —               | —                | —             | 0.05             |
| Phosphorous . . . . .    | —         | —         | 0.13            | —                | —             | —                |
| Iron . . . . .           | Traces    | 0.07      | 0.08            | 0.11             | 0.31          | —                |
| Lead . . . . .           | Traces    | Nil       | Nil             | 0.10             | Nil           | —                |
| Manganese . . . . .      | Traces    | —         | 0.06            | 0.06             | 0.05          | —                |
| Hardness DPN/5 . . . . . | —         | 190       | 197             | 210              | 200           | 265              |

suitable electroplate coating of cadmium, tin or silver can enable this to be achieved. Again, metallising may be necessary to allow a bimetallic junction to be used safely without exceeding a value of 0.25 volts for the contact potential between the coatings.

These brief notes should answer the question that naturally arises—namely, why plate a corrosion-resisting metal? Regarding cleaning by pickling processes, this is not only entailed preparatory to any electroplating operation, but it is necessary for the conditioning of components after heat-treatment operations as well as for the general neatening of surfaces to a presentable condition. The tarnish, or the oxide film from heat-treatment, on the beryllium coppers is rather more refractory than that on the other non-ferrous metals such as the coppers, brasses, nickel silvers, and phosphor bronzes. This is due to the influence of the beryllium, in much the same way as the aluminium constituent in aluminium bronzes creates a tenacious oxide film and imparts corrosion resistance to this series of alloys. Pickling is, therefore, a little more difficult than with the coppers, brasses, etc., and a little more attention is required to ensure efficiency without the risk of badly pitted and difficultly plated surfaces.

#### Heat-treatment

The most used beryllium copper for all types of springs is that containing about 2% of beryllium, with small additions of metals such as cobalt, nickel or silicon to restrict grain growth during annealing and to aid precipitation during the hardening heat-treatment. The compositional limits for a typical heat-treatable alloy are as under:—

| Composition                                      | Nominal | Min. | Max. |
|--|---------|------|------|
| %  |         |      |      |
| Beryllium . . . .                                | 2.0     | 1.90 | 2.25 |
| Cobalt . . . . .                                 | 0.5     | 0.25 | 0.75 |
| Silicon . . . . .                                | 0.1     | 0.05 | 0.15 |
| Total impurities including iron and lead . . . . | —       | —    | 0.35 |

Wire and strip material of this composition is available in tempers ranging from annealed to spring hard, selection depending upon the configuration of the component to be fabricated. The hardness ranges for these tempers are as follows:—

|                        |                   |
|------------------------|-------------------|
| Annealed . . . . .     | Up to 120 D.P.N.  |
| Quarter hard . . . . . | 120 to 185 D.P.N. |
| Half hard . . . . .    | 185 to 225 D.P.N. |
| Spring hard . . . . .  | Over 225 D.P.N.   |

Forms requiring severe upset or very sharp bends would use annealed material. The majority of components involving reasonably severe operations would employ the quarter hard temper. Half hard temper can only be used for shallow upsets or moderate forms. The hard material only permits of very gentle bends and the like. As far as practicable, of course, the harder tempers are used. In all cases, rapid work-hardening results from mechanical working, and therefore, in some cases heat-treatment for hardening can be omitted. On the other hand, for very severe working, intermediate annealing is often necessitated. All such components, and those made from the annealed temper material, must be finally subjected to the hardening heat-treatment process.

The annealing process comprises soaking the work for 20–30 minutes at a temperature of 800° C. plus or minus 10° C., and then quenching in water. It is preferable to use a controlled neutral or reducing atmosphere in the furnace, but this is not usual, and consequently much black oxidation occurs. It is this annealing oxide which is most difficult to remove.

The precipitation-hardening process consists in soaking the work for 1–2 hours at a temperature from 300°–320° C. and then quenching in water or cooling in air. Fully-annealed work is given the longer time and upper temperature. Again, a controlled atmosphere is desirable but is probably rarely used. Consequently oxidation occurs, but not so seriously as it does in the annealing process, although the oxide film formed is still quite refractory.

TABLE V.—COMPOSITION AND HARDNESS CHARACTERISTICS OF BERYLLIUM COPPERS OF VARIOUS SIZES

| Material                         | Hardness D.P.N. |          | Composition % |        |         |
|----------------------------------|-----------------|----------|---------------|--------|---------|
|                                  | As Received     | Hardened | Beryllium     | Cobalt | Silicon |
| 0.005 in. thick strips . . . . . | 180             | 340      | 2.08          | 0.32   | 0.10    |
| 0.010 in. . . . .                | 176             | 362      | 1.98          | 0.41   | 0.08    |
| 0.012 in. . . . .                | 193             | 410      | 1.90          | 0.38   | 0.05    |
| 0.016 in. . . . .                | 180             | 398      | 1.95          | 0.15   | 0.14    |
| 0.018 in. . . . .                | 173             | 356      | 2.03          | 0.05   | 0.07    |
| 0.022 in. . . . .                | 260             | 400      | 1.90          | 0.31   | 0.05    |
| 1 in. dia. rod . . . . .         | 250             | 393      | 2.06          | 0.32   | 0.04    |
| ½ in. × ⅜ in. bar . . . . .      | 183             | 374      | 2.10          | 0.50   | 0.04    |

Table V presents the composition and hardness characteristics (before and after hardening) of commercial beryllium coppers in a range of sizes.

### Pickling

To assist in the removal of annealing scale, it is often recommended that the subsequent pressing operations should be performed before pickling in order to fracture the oxide film and render it more easily attacked. This is not always favoured, as the scale may be drawn or pressed into the surface of the component and cause irregularities in the surface when ultimately pickled, and it may also promote undue wear on the tools. Consequently, it is recommended that both annealing and hardening scales should be removed immediately after these heat-treatments: further, that they should be removed in dilute sulphuric acid solutions, and that, if useful, a further acid treatment should be given using dilute sulphuric acid containing an oxidising agent in order to produce a clean uniform appearance.

Prior to heat-treatment, the components should be cleaned to remove all traces of lubricant or grease, as well as swarf: the former would burn and carbonise, and the latter may become sintered or welded to the component during heat-treatment, and so add to subsequent cleaning operations. Trichlorethylene vapour degreasing is sufficient for oil or liquor/vapour for oil and swarf. Soap greases need aqueous alkali cleaning. The latter need only be mild, such as a 5% solution of equal weights of soda ash and sodium metasilicate, the solution being operated short of boiling.

After heat-treatment, only the acid pickling is necessary unless the work has been allowed to be contaminated with oil or grease, in which case the mild alkali clean must first be applied. For the acid clean, it has been found that commercial concentrated sulphuric acid (S.G.1.85) at various dilutions in water is the most efficient. If the solution can be heated, much more rapid cleaning is achieved, and the following summarises the possibilities as far as pickling *hardening* scale is concerned:—

Using 10% by volume (1 part sulphuric acid, 9 parts water) acid solution at a temperature of 90°–100° C., the immersion period required is a matter of seconds for normal films, and well under a minute for the most tenacious of films. The lower the temperature, the longer is the time period required for complete removal of the oxide coating. At 50° C. up to 2 minutes may be required, and at room temperature (20°–25° C.), as long as 20 minutes may be necessary.

Using stronger acid solutions, the rate of cleaning at elevated temperatures is increased, so that in, for example, 25–30% by volume acid, a few seconds immersion at 100° C. suffices. The rate of cleaning at room temperature is not however accelerated.

Consequently, the 10% sulphuric-acid concentration is advocated, with the elevated temperature if convenient, but at room temperature otherwise. There is no real objection to cold pickling, and as the acid only dissolves oxide, there is no attack whatsoever on the beryllium copper itself. Hence, there is no fear of over-pickling and damage to dimensions by excessively long immersion times.

For *annealing* scale, the hot 10% sulphuric-acid solution is necessary to remove the oxide coating in a reasonable time. The cleaning is efficient insofar as all the oxide film is removed chemically without mechanical

aids such as wire-brushing, but the cleaned surface is dull and patchy, with irregular coppery stains.

This process of cleaning is similar to that employed for copper, brass, phosphor bronze and nickel silver under similar conditions. That is as far as the similarity goes, and it cannot be too strongly stressed that this simple acid cleaning should be carried out to completion —i.e., till the black oxide has completely disappeared, before any acid solution containing an oxidising agent is applied. Thus strong nitro-sulphuric acid mixtures, and dilute sulphuric-acid solutions containing dichromate, are used for cleaning the other copper-rich non-ferrous metals, but they should *not* be used for the beryllium coppers before all the black oxide has first been removed in dilute sulphuric acid. Otherwise surface pitting will result, and this can be very severe in a short treatment time, with adverse effects not only upon appearance, but also upon dimensions and, when it is involved, wear.

This acid clean is sufficient prior to further press-shop operations, but the final clean from the heat-treatment shop should include one in the oxidising acid mixture to provide uniformity of appearance. Various solutions have been suggested for this purpose, including strong nitric/sulphuric acid mixtures with or without the addition of 0.1% by weight of hydrochloric acid, and dilute sulphuric-acid solutions containing copper sulphate, and these are by no means satisfactory. The best formulation is considered to be 5% by volume of sulphuric acid with the addition of 2–3% of potassium or sodium dichromate, and this is deemed to be entirely satisfactory at room temperatures. An immersion period of from 1–2 minutes at 20°–25° C. is sufficiently prolonged to remove coppery stains and to transform the rather dirty appearance of the sulphuric pickled work to a relatively bright, uniform and neat coppery-like finish. It is, therefore, advocated that the sulphuric pickle should always be followed by a sulphuric-dichromate treatment. The time of immersion in the latter should be maintained at the minimum required to give a neat appearance because slight attack on the base metal does occur in this mixture.

After each acid treatment, naturally, thorough water washing is necessary. A thorough wash in cold running water and a rinse in running hot water, followed by drying off in hot sawdust, by oven heat or by hot air comprise the ideal sequence of operations.

### Cleaning for Plating

Before dealing with electroplating processes as applied to beryllium-copper components, it must be stressed that plating directly following the dilute sulphuric acid/sodium or potassium dichromate is unsatisfactory because the electroplated coating has a very poor adhesion. This is not an unusual phenomenon, even traces of chromic acid in wash waters having been found to impair the adherence of, for example, nickel coatings. Alkali treatment, electrolytic or otherwise, is insufficient to counteract the influence of the dichromate pickle or to remove the thin oxide film that it apparently forms on the surface of the components. A suitable acid treatment is necessary, and a nitro/sulphuric process has proved to be effective for this purpose.

Work for plating may reach the finishing shop direct from machine shops without having been subjected to any heat-treatment operations, or direct from the heat-treatment shop after hardening, or again from the machine shops due to some forming, drilling or other

operations having been performed after one of the heat-treatments. It should be ensured that all black oxide scale has been completely removed by the dilute sulphuric-acid process already described; when this is not the case, the recommended processes should be applied for this purpose. Assuming that this point has been properly attended to, the only extraneous contamination to be removed will be oil, grease and swarf. Liquor/vapour trichlorethylene degreasing is sufficient to take care of this, but if plant is not available adjacent to the plating equipment for this operation, aqueous alkali can be utilised quite effectively. Any of the mild alkalies normally employed on plating lines suffices. A typical average composition likely to be available on any plating shop line, is 8-16 oz. per gal. of the following mixture:—

|                             |         |
|-----------------------------|---------|
| Sodium Carbonate .. .. .    | 3 parts |
| Sodium Metasilicate .. .. . | 3 parts |
| Trisodium Phosphate .. .. . | 1 part  |

This is operated short of boiling and is followed by water rinsing. It is followed by two quick nitro-sulphuric acid dips. The first of these uses a mixture of 3 parts by volume of nitric acid and 1 part of sulphuric acid (commercial concentrated acids) at shop temperature. The second comprises a mixture of 3 parts of sulphuric acid and 1 part of nitric acid. A cold-water rinse is interposed between the two acid dips, and a thorough cold water wash after the second dip. If the plating required uses an acid electrolyte, electroplating follows immediately without allowing the work to dry-off whereby it would tarnish or stain, which is detrimental to adhesion. When the electrolyte concerned is alkaline, the work is rinsed in a cold solution of sodium cyanide (8-oz./gal.), and rinsed thoroughly in cold running water before being transferred quickly without tarnishing to the plating bath.

### Coatings Used

As already indicated, electroplating is required on beryllium-copper components for various reasons, and these are very briefly reviewed below:—

1. For preserving a neat "white" finish under service conditions that are not too extreme in corrosive severity, nickel plating has in the past been regarded as the most suitable finish, but in more recent years it has been extensively supplanted by tin. While nickel becomes somewhat yellowish under exposure conditions of mild humidity and temperature fluctuations, its passivity breaks down under more severe circumstances, particularly when chemical corrodants are present. Under such conditions the nickel ceases to provide good protection to the base metal. Tin plate from modern electrolytes not only provides a near white finish which retains this appearance under mild corroding conditions, but it gives sacrificial protection in severely adverse environments. In addition, it provides an excellent base for soft soldering using non-corrosive resin base fluxes. This is a very important feature in instrument work and in electrical applications. Again, tin is a very useful coating where bimetallic junctions are involved because its electro-chemical potential falls in an intermediate position relative to those of many metals concerned in assemblies.
2. For high-frequency conductance, and for low-contact resistance, silver plate is normally necessary. This has a neat appearance which is retained if the plating, after drying off, is slushed with mineral

jelly in very dilute petroleum solution. The jelly does not interfere with electrical contact, nor with soft soldering with resin fluxes. When a good-wearing surface is required in conjunction with retention of brilliancy of appearance, and low contact resistance, the silver is over-plated with rhodium.

3. For electrical contact reasons, particularly for very low resistance at very light pressures (e.g., tiny spring clips), gold plating is used. This may be gold directly applied, or a copper, silver or nickel underlay with a gold top coat.
4. For levelling differences of potential at bimetallic junctions, zinc or cadmium are sometimes sought, but their use is not advocated unless essential. Cadmium is not necessary for soldering because tin is satisfactory for this purpose, and is a superior choice for other reasons. Zinc and cadmium are both too electropositive to be stable on a copper-rich alloy; they tend to diffuse into the base metal, and to corrode with extreme rapidity under humid conditions.

No temper or hydrogen embrittlement of beryllium copper has been recorded from chemical and electro-chemical processing, and therefore, no detrimental influence whatsoever upon springiness or fatigue resistance is to be anticipated.

The usual techniques and electrolytes appertain for the actual plating operations provided that these are sound and controlled to maintain them constant—viz., solutions held to specified compositions by analysis, area of the load calculated to ensure use of proper amperage, and final washing and drying adequately performed. Typical conditions for miscellaneous types of components are given below for the various metal platings cited.

### Tin Plating

The stannate electrolyte is recommended for all plants that can be operated hot (80° C.). The electrolyte is strongly alkaline in reaction which in itself takes care of any minor deficiencies in pre-cleaning.

The stannate tin electrolyte is prepared from 16 oz. of sodium stannate (hydrated form) per gallon of solution and adjusted with caustic soda to correspond to 2.5 oz. of free caustic soda per gal. It is operated at 80° C. plus or minus 5° C., and with a cathode current density of 15-20 amps./sq. ft. Cast tin anodes are used, and they are "filmed" before use. This is achieved by loading the work into the vat and then lowering the anodes, connected by flexible leads to the supply line, slowly into the vat with the potential switched on. The high current density conditions cause a greenish-yellow film to form on the anodes.

The sulphate tin process uses an acid electrolyte of stannous sulphate and cresol-sulphonic acid, with gelatin and beta naphthol additions, and it is maintained to the following composition per gallon by analytical control:—

|                               |                   |
|-------------------------------|-------------------|
| Stannous Sulphate .. .. .     | 9 oz.             |
| Cresol Sulphonic Acid .. .. . | 16 oz.            |
| Free Sulphuric Acid .. .. .   | 9.5 oz.           |
| Gelatin .. .. .               | $\frac{1}{2}$ oz. |
| Beta Naphthol .. .. .         | $\frac{1}{4}$ oz. |

Cast tin anodes are used, and a cathode current density up to 10 amps./sq. ft.

As previously mentioned, a strong advantage of this solution is the fact that it is operated at shop temperature.



The preferred thickness of tin coating to be applied for the purposes indicated is within the range 0.0003-0.0006 in.

### Nickel Plating

For the normal type of nickel plating, a single nickel salts/chloride electrolyte is used as follows:—

|                                |         |
|--------------------------------|---------|
| Nickel Sulphate Crystals .. .. | 48 oz.  |
| Nickel Chloride Crystals .. .. | 3 oz.   |
| Boric Acid .. ..               | 2.5 oz. |
| Water to make .. ..            | 1 gal.  |

This is operated warm at 35°-40° C. with a cathode current density of 10-15 amps./sq. ft., and it is maintained to a pH value of 5.6-5.8. The average thickness of nickel coating applied is from 0.0001-0.0003 in.

The bright type of nickel plate can be deposited from a cobalt containing electrolyte, viz.:—

|                                |         |
|--------------------------------|---------|
| Nickel Sulphate Crystals .. .. | 32 oz.  |
| Cobalt Sulphate .. ..          | 2 oz.   |
| Boric Acid .. ..               | 4 oz.   |
| Nickel Chloride .. ..          | 6 oz.   |
| Sodium Formate .. ..           | 4.5 oz. |
| Water to make .. ..            | 1 gal.  |

This is controlled to a pH value of 5.0-5.5, operated at 55°-60° C. and with a cathode current density of 40-80 amps./sq. ft.

Organic brighteners may also be used, but these are more difficult to control. Such electrolytes are prepared from 24-48 oz. of nickel-sulphate crystals, 5-10 oz. of nickel-chloride crystals, 5-6.5 oz. of boric acid, per gallon, and brightener to suit according to type. They are controlled in pH within the range 2.5-5.0, operated at temperatures from 30°-70° C., and at cathode current densities from 5-120 amps./sq. ft.

Depassive nickel anodes are employed in all these nickelling processes.

### Silver Plating

In silver plating, some platers prefer to "strike" with silver before applying the main coating. For this, a solution of 1-1.5 oz. of double potassium-silver cyanide (54% silver content) and 20 oz. of sodium cyanide per gal. is used at room temperature, with a voltage of 6 volts. The plating can be applied direct, or after striking, from the following solution:—

|                                |         |
|--------------------------------|---------|
| Potassium Silver Cyanide .. .. | 6.5 oz. |
| Potassium Cyanide .. ..        | 3.5 oz. |
| Potassium Carbonate .. ..      | 6 oz.   |
| Water to make .. ..            | 1 gal.  |

A rocking cathode is preferred, a cathode current density of 3-6 amps./sq. ft. is used, and the solution is used at room temperature. Patented bright silver-plating solutions can use from 10-30 amps./sq. ft. or even higher. Anodes of fine silver are employed.

The usual thickness of silver plating to apply is 0.0002-0.0004 in., but thicker coatings may be needed for the higher frequencies in radio applications. When rhodium is additionally needed, this is applied over the silver from a proprietary rhodium solution at a cathode current density of about 10 amps./sq. ft. and an electrolyte temperature of 35°-40° C. The thickness applied merely for brightness or contact resistance is of the order of 0.00002 in. and for wear resistance 0.00010 in. or greater.

### Gold Plating

Gold can be applied directly from a gold cyanide bath—viz.:—

|                      |          |
|----------------------|----------|
| Aurous Cyanide .. .. | 1.5 oz.  |
| Sodium Cyanide .. .. | 2.25 oz. |
| Water to make .. ..  | 1 gal.   |

This is operated warm at 55°-60° C., using a rocking cathode and from 4-15 amps./sq. ft. of cathode surface. Anodes have to be of 24 carat gold. A thickness from 0.0001-0.0002 in. is ample for normal purposes.

### Copper Plating

When copper is applied under silver for heavier deposits for radio-frequency reasons, this may be applied from a sulphate or a Rochelle salt electrolyte. Pure copper anodes are employed, and the sulphate electrolyte comprises the following:—

|                                |        |
|--------------------------------|--------|
| Copper Sulphate Crystals .. .. | 32 oz. |
| Sulphuric Acid .. ..           | 5 oz.  |
| Water to make .. ..            | 1 gal. |

It is operated at shop temperature (15°-25° C.) and with a cathode current density within the range of 10-25 amps./sq. ft.

The Rochelle salt process uses a modified cyanide electrolyte, viz.:—

|                             |        |
|-----------------------------|--------|
| Sodium Cyanide .. ..        | 4 oz.  |
| Single Copper Cyanide .. .. | 3 oz.  |
| Sodium Carbonate .. ..      | 2 oz.  |
| Rochelle Salt .. ..         | 8 oz.  |
| Water to make .. ..         | 1 gal. |

An anode area of at least twice the cathode area is used, and the solution controlled to give a free sodium-cyanide content of 0.5-1.0 oz./gal. The solution is kept at 50°-60° C. The cathode current density employed is 30-40 amps./sq. ft., and the anode C.D. less than 20 amps./sq. ft. A rocking cathode is advocated.

Any of the above platings applied to beryllium-copper components that have not been subjected to any heat-treatment processes, or to those that have been heat-treated and sulphuric acid pickled followed by sulphuric/dichromate treatment, are quite satisfactory and adhere tenaciously provided that the nitro/sulphuric acid treatment is given prior to plating. If this is not applied adhesion will be poor, or, at the best, indifferent.

## Henry Wiggin & Co. Ltd., Tube Production

HENRY WIGGIN & CO., LTD., Birmingham, who are the largest producers of wrought-nickel products in Europe, announce that delivery of Monel, nickel and Inconel tubes has been considerably accelerated. Whereas at the beginning of last year orders were subject to nine to twelve months delay, they are now able to execute orders in a matter of some two to three months.

Readers will be interested to note the recent publication of a revised edition of their brochure, "Fabrication of Monel, Nickel and Inconel Seamless Pipe and Tubing," which lists full details of the very ample range of sizes available in these three corrosion-resisting materials. Copies of this publication can be obtained by writing direct to Henry Wiggin & Co., Ltd., Grosvenor House, Park Lane, London, W.1.



## Staff Changes and Appointments

Mr. C. G. CONWAY has resigned from his position as Metallurgical Engineer with The Mond Nickel Co., Ltd., to take up an appointment as General Consultant with Power Jets, Ltd., 8, Hamilton Place, London, W.1.

Mr. J. G. PEARCE has been awarded the honorary degree of Dr. Ing., by the Senate of the Rheinisch-Westfälische Technische Hochschule, Aachen.

Mr. L. L. ROSS is now Technical Director of Messrs. Elliott Bros. (London), Ltd., of Lewisham, London, S.E. 13.

Mr. W. T. AGAR has been appointed to the board of B. and S. Massey, Ltd.

PROFESSOR R. J. SARJANT has been appointed Chairman of the recently formed Sheffield Panel of the British Coal Utilisation Research Association, Shell Type Boiler and Firing Equipment Committee.

Mr. R. Y. PARKINSON, formerly Sales Manager, has been appointed Special Director (Sales) of Ribblesdale Cement, Ltd. Mr. Parkinson is also a director of the Horrocksford Lime Co., Ltd., and of the Bold Venture Lime Co., Ltd.

Mr. E. AUSTYN REYNOLDS, Mr. J. H. CATLING, and Mr. W. H. BOWMAN have been appointed Executive Directors of TI Aluminium, Ltd., the new subsidiary of Tube Investments, Ltd., which has been formed to co-ordinate the administrative, research and marketing organisations of the Group's Aluminium Division, comprising Reynolds Light Alloys, Ltd., Reynolds Rolling Mills, Ltd., and The South Wales Aluminium Co., Ltd.

Mr. ANDREW BLYTH recently resigned his position as Sales Manager of High Duty Alloys, Ltd., Slough, and has taken up an appointment as General Manager of William Mills, Ltd., Wednesbury.

Mr. J. R. GREGG has resigned from the board of the Round Oak Steel Works, Ltd.

Mr. H. J. PENN has been appointed General Manager of the Murex group of companies.

Mr. V. C. McDONNELL, M.I.Mech.E., formerly Production Manager, Development and Research Division of the De Havilland Engine Co., Ltd., has been appointed Development Manager to Conrad Parlanti Castings, Herne Bay, Kent.

Mr. A. B. ALLISON, Ironworks Manager of the Shotts Iron Co., Ltd., has retired after 30 years' service.

Mr. W. G. WALLACE, Secretary of Sanderson Bros. and Newbould, Ltd., has been made a Director.

Mr. E. S. WADDINGTON, F.S.E., M.Inst.W., A.M.I.E.E. (s.a.), Associate I.E.E., of the Industrial Department of Philips Electrical, Ltd., has had the honour of being elected President, for 1949, of the Society of Engineers (Incorporated), of which he has been a Vice-President for some years.

Mr. A. CIBULA, B.A., has been appointed an Investigator with the British Non-Ferrous Metals Research Association.

Dr. L. WHITBY, M.Sc., F.R.I.C., has relinquished his post as Chief Research Chemist to High Duty Alloys, Ltd., Slough, Bucks., and has been appointed Director of the Paint Industries Research Institute, Durban, South Africa. For several years Dr. Whitby was head of Technical Division, Paint Research Station, Teddington.

Mr. A. J. K. HONEYMAN has relinquished his position as Deputy Chief Metallurgist to Messrs. Colvilles, Ltd., to take up an appointment as Chief Metallurgist of the Steel Division of The Steel Company of Wales.

PROFESSOR N. P. GANDHI, M.A., B.Sc., A.R.S.M., D.I.C., M.I.M.M., has been appointed Chairman of the Basic Non-Ferrous Metals Sectional Committee of the Indian Standards Institution, and also a representative of the Indian Institute of Metals on the Non-Ferrous Metals Industry Development Committee set up by the Government of India.

SIR ELLIS HUNTER has been re-elected President of the British Iron and Steel Federation for the forthcoming year. Sir Ellis is Chairman and Managing Director of Dorman, Long & Co., Ltd.

Mr. G. H. LATHAM, Chairman of the Whitehead Iron and Steel Co., Ltd., was re-appointed to the office of Past-President. Mr. N. H. ROLLASON, Managing Director of John Summers & Sons, Ltd., was re-elected to the post of President-Elect.

Mr. CHARLES SMITH has been appointed a local Director of John Smith (Keighley), Ltd., the Yorkshire crane makers. Charles, a grandson of John Smith, the founder of the firm, which was established in 1866, has been with the company more than 30 years.

## Awards

Mr. J. A. KILBY and Mr. W. G. CAMERON have been awarded a Premium by the Institution of Engineers and Shipbuilders in Scotland, for their paper; "Recent Developments in Steel Processing."

Dr. J. TAYLOR has been awarded the Riley Medal by the West of Scotland Iron and Steel Institute, for his paper, "Effect of Operating Conditions on Type of Reduction and Carbon Rates in the Blast Furnace."

The honorary degree of Doctor of Science has been conferred by Leeds University on Mr. A. T. GREEN, Director of the British Ceramic Research Association. Mr. IVOR JENKINS, F.I.M., was recently awarded the degree of Doctor of Science of the University of Wales for work in the field of metallurgy.

Dr. G. V. RAYNOR, M.A., has been awarded the degree of D.Sc. of Oxford University.

Mr. T. BROOM, B.A., has been awarded a Goldsmith's Dominions Travelling Scholarship and will be working for two years, under the direction of Dr. W. Boas, in the Division of Tribophysics, Council for Scientific and Industrial Research, Melbourne University.

## Obituary — Mr. Bernard W. Methley

Mr. Bernard W. Methley died at his home in Rotherham on January 14th at the age of 72. He was on the staff of Steel, Peech & Tozer for 46 years, and when he retired from the position of chief chemist in 1947 he became a consultant to the Research and Development Department of the parent firm, The United Steel Companies, Ltd. He was a past-president of the South Yorkshire and North Midland section of the Royal Institute of Chemistry, a Fellow of the Institution of Metallurgists, and a member of the Iron and Steel Institute and the Sheffield Metallurgical Association. He was well known to chemists and metallurgists all over the country and highly respected by a wide circle of colleagues and friends.

Mr. Methley was a keen golfer, and in his younger days an enthusiastic yachtsman. He leaves a widow and one daughter.

# Dynamic Torsion of Metals and Alloys Used in Aircraft Construction

## Their Elastic Limit and Micro-plastic Deformation Under Reversed Torsional Energy Loads\*—Part I

By Georges Welter

*Professor of Applied Mechanics, Ecole Polytechnique, Montreal*

*In modern machinery practically all elements work under short-time repeated loading, and little data is available about the mechanical properties of structural materials investigated under these conditions. The present research has been carried out to investigate the maximum possible impact loads causing no permanent micro-deformation of the test specimen under plus and minus torsion loads. In addition to the static properties, the dynamic loads necessary to attain the first permanent deformations, as well as those up to the yielding of the material, have been investigated. A specially devised torsional-testing impact machine used for applying repeated and increasing dynamic loads is described.*

### Introduction

SO long as structural materials were used under static loads (as for instance, in bridges, buildings, ships, transmission towers, etc.), there was little interest shown in their behaviour under dynamic conditions. A great many materials are, however, used at present in high-speed machines under loading conditions that are quite different from those of statically loaded structures. It seems, therefore, that it is becoming more and more necessary to measure the performance of the materials by new methods which are especially designed to study these dynamic high-speed loads. These methods are generally based on new laboratory facilities which differ in an important respect from the usual static-load tests.

In fact, in modern times the industrial requirements of testing are mostly of a dynamic character, and it is necessary to apply loads of very short duration in order to become acquainted with the dynamic properties of the materials. Practically all elements used in modern machinery are working under short-time repeated loading, and yet we are not able to find in applied literature data about the mechanical properties of structural materials investigated under these conditions. In general we ought to know much more about the elastic and micro-plastic properties of modern materials used in high-speed, efficient machinery in relation to their maximum impact loads applied to these

materials under different types of loading. There are, indeed, only a few metallurgical research institutes making studies about the behaviour of structural materials under dynamic conditions. There is insufficient test data available by which to safely build structural and machine members, subject to dynamic loads of different types. Torsion is a type of loading which is frequently encountered in mobile structures, and an investigation of this phase does not seem without interest.

In this research we intend to investigate the maximum possible impact loads causing no permanent micro-deformation of the test specimen under plus and minus torsion loads.† Besides the static properties, the dynamic loads necessary to attain the first permanent deformations, as well as those up to the yielding of the materials, have been investigated. For this purpose a specially-devised torsional testing impact machine has been used in applying repeated and increasing dynamic loads to the specimen in both senses. The means of loading the specimens in the plus and minus senses, has been chosen in order to submit materials having undergone small permanent deformations by a previous loading, to increasing dynamic loads in the opposite sense. By this procedure it becomes possible to study the "effect of Bauschinger" on different metals and alloys. Bauschinger<sup>1</sup> found, in 1881, that the proportional

limit of steel can be changed in large measure; it can be raised by small preliminary permanent deformations in tension, or it can be diminished by an axial cold deformation in the opposite sense, that is, under compression loads. Later on, this effect was investigated by Mr. Van den Brook<sup>2</sup> who, making his experiments with steel, found in 1918 that the effect of Bauschinger is of fundamental importance for mild steel. Later on, in 1925, G. Masing<sup>3</sup> investigated this effect on non-ferrous materials. At about the same time, some preliminary tests with specimens under dynamic-torsion stresses were carried out by the author.<sup>4</sup>

To measure small torsion effects the specimens for this investigation are equipped, at a constant gauge length, with two mirrors, indicating, by means of scales and telescopes, their deformation. The energy load was applied either by using a constant mass and an increasing speed, or by using a constant speed and increasing masses. For this research work materials commonly used in aircraft, as light and ultra-light alloys, have been investigated in comparison with structural steels and Monel metal under static and dynamic loads.

### Testing Method and Apparatus

A special testing method had to be developed, and the measurement of extremely small elastic and plastic deformations under torsional static and dynamic loads, applied in both

\* This investigation was made possible through funds from the National Research Council, Ottawa (Committee on Assisted Researches), for which the author here wishes to express his gratitude. The author appreciates also the valuable assistance of Mr. E. A. Monti, who carried out the experimental part of this investigation, representing a part of his Doctor thesis.

† From a private correspondence with an outstanding authority in this field, the opinion was prevailing that the elastic limit of the material is not influenced by the kind of loading, and no important difference in this limit between statically and dynamically-loaded materials should exist.

1 Bauschinger, J., *Zerlegung*, 27, 1881, pp. 289-348, *Mitteilungen Mech. Techn. Labor München* 13, 1886.

2 Van den Brook, J. A. *Carnegie Scholarship Memoirs*, Vol. IX, 1918, also *Engineering*, July, 1918.

3 Masing, G., *Zeitschrift für techn. Phys.* 8, 1925, pp. 849-873; *Wiss. Ver. Siemens Konzern* 5, 1926, pp. 135-141.

4 Welter, G., *Zeitschrift für Metallkunde*, 1925, pp. 285-298.

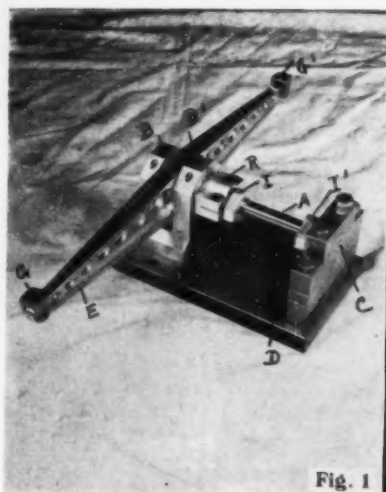


Fig. 1

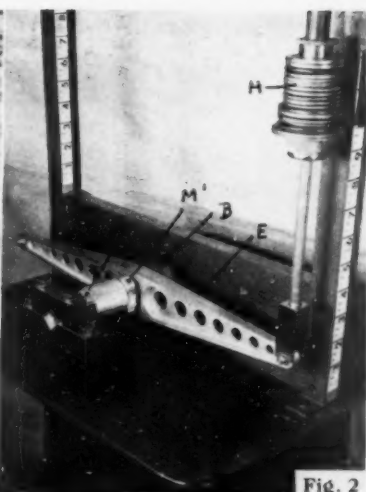


Fig. 2

positive and negative sense, was fundamental for this investigation. The sensitivity and accuracy of the apparatus had to be the highest possible, because the elastic and micro-plastic deformations of the specimens, taking place only in the external layers of the cylindrical-gauge length, were naturally extremely small. As there is no commercial apparatus available for this kind of investigation, the device for producing impact loads as well as static loads under torsion, together with the device for measuring micro-deformations of the smallest possible amount, was newly designed and constructed by the Testing Materials laboratory of Ecole Polytechnique. As may be seen in Fig. 1, this apparatus consists of a horizontal-cylindrical test specimen A, supported at one end by double-collar needle bearings B-B'. The other end, which is about 6 in. removed, is rigidly fixed, by means of a square C, to the base plate D of the apparatus. This double-needle bearing B-B' represents an improvement over the first model illustrated in Fig. 2. This latter device had only one ball bearing B, insufficient to eliminate possible additional harmful bending moment in the loaded specimen produced by the lever E. To produce only a pure torsion moment in the specimen, the light metal double-lever arm E was, therefore, placed between two needle bearings B-B' (Fig. 1). This lever E, with a length of 12 in. from centre to loading point, was made as light as possible in order to avoid detrimental mass effects. Both ends of this double-lever E are provided with an adjustable small steel block with spherical face G-G' on which the impact hammer transmits

its energy (Fig. 1). This energy is produced by a variable weight H falling from different heights with different speeds on the far end of the

lever (Figs. 1 and 2). The static load is applied by increasing weights placed on disc M attached to a vertical thin rod N, which can be connected at both ends to the light metal double-lever E (Fig. 7). By a small sensitive optical device with mirrors I-I' (Fig. 1), the measurement of a deflection of an angle of a few seconds is possible by means of scales K and telescopes L, as shown in Fig. 3. This may also be accomplished as shown in another set-up according to Figs. 6 and 7.

Preliminary tests made with aluminium alloy and steel specimens showed the possibility of recording, with this device, interesting load-deflection diagrams by torsion-impact loads in comparison to static-torsion loads. Based on these preliminary results, however, some fundamental changes of a few parts of this device were necessary in order to avoid additional critical torsion moments in the specimens due to harmful vibrations of the whole system when heavy impact loads are applied. In order to reduce detrimental mass effects, a shorter-light metal lever arm with a mass moment of only about 1-4, as compared with the first model, has been used. Furthermore, to obtain a closer control over the basic permanent micro-deformations in torsion, a new optical device M-M', visible in Fig. 2, has been developed. The measurements of the deformations made by the optical device were, for a few tests, checked by an electrical strain gauge SR-4 with "rosette"

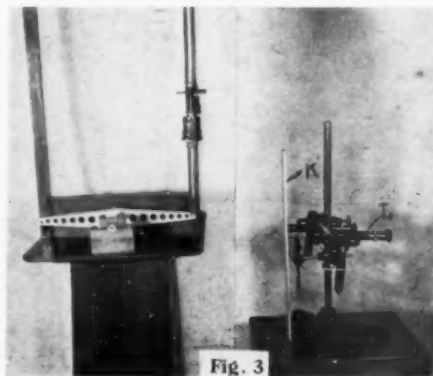


Fig. 3

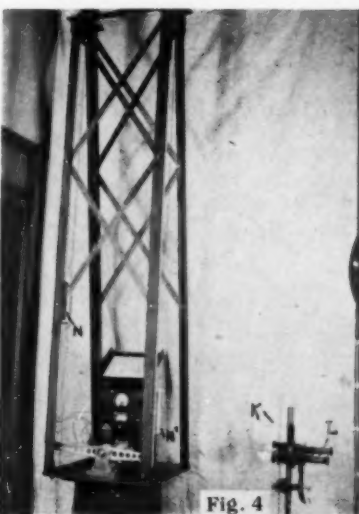


Fig. 4

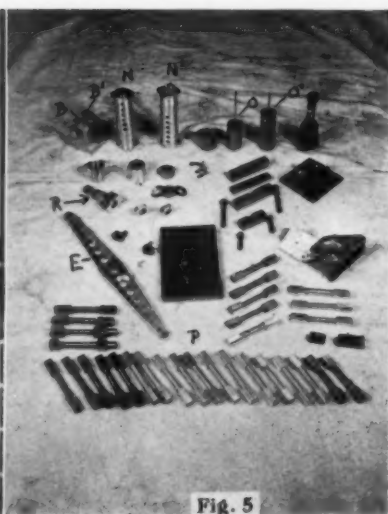


Fig. 5



glued on the specimen. The modified apparatus for these check tests is represented in Fig. 4 and some details, as the new light metal hammers N-N', the additional weights O-O', and some test specimens P, used for this investigation, are visible in Fig. 5. The test results with this arrangement were, however, not satisfactory. Difficulties, especially with the strain gauge glued on the specimen, arose, showing results which were not at all in accordance with those of the mirror torsionmeter. It seems as if the glue of the strain gauge does not satisfactorily withstand the dynamic impact loads and vibrations of the specimen. This device has been abandoned and replaced by a new one. The final model of the twin-dynamic torsion apparatus used for the main static and dynamic tests, which had to be carried out under positive and negative torsion loads, is shown in Fig. 6. In these pictures the shorter double-light metal lever A (length from centre to end, 2 in.), one of the double hammers B-B' (dead weight,  $\frac{1}{2}$  lb.) for the dynamic loading device, the torsionmeter C-C', as well as the scales D indicating the dropping height and telescopes L, are visible. In Fig. 7 the whole set-up, as used for static and dynamic torsion tests, is represented. For these static tests we used the longer lever E, at the end of which the suspended weights are gradually increased; for each static load the deflection indicated by the mirrors is observed by means of telescopes L and measuring scales K. The maximum dynamic load which could be applied by this apparatus was 8 lb. By changing the weights from  $\frac{1}{2}$ -8 lb. and

by using a height of drop of 1 in. to several feet, the impact capacity of the apparatus could be changed from  $\frac{1}{2}$  in.-lb. to 400 in.-lb. The micro-deformations were measured very accurately by the described optical torsionmeter. In fact, the smallest

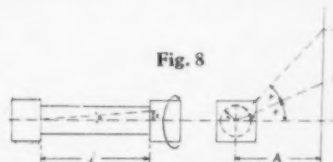


Fig. 8

possible reading on the scale by means of the telescopes was 0.1 mm., using a radius from the centre of the specimen to the scale of 1,000 mm. According to Fig. 8, the deformation of the specimen of an angle of  $2a$  expressed in radians is:

$$1/10,000 \text{ or } a = 1/20,000 \text{ rad.}$$

On the other hand, if  $e$  represents the arc of which the specimen is twisted, and  $r$  the radius of the specimen (which was  $\frac{7}{16}$  in. dia.), we will have:

$$a = \frac{e}{r} \text{ and } e = a \times r = \frac{1}{20,000} \times r \\ = \frac{1}{20,000} \times \frac{7}{16} = \frac{0.212}{20,000}$$

Furthermore, the shearing unit strain  $\epsilon$  at the surface of the cylindrical specimen when twisted, is:

$$\epsilon = \tan \phi;$$

if the gauge length  $l$  of the specimen is  $2\frac{1}{2}$  in., we will have:

$$\epsilon = \frac{e}{l} = \frac{0.212}{20,000 \times 2\frac{1}{2}} = \\ 0.0000044 \text{ in./in.}$$

In unit length of 1 in., a minimum permanent strain at the surface of the specimen of 4.4 millionths of an inch can be measured. This means that

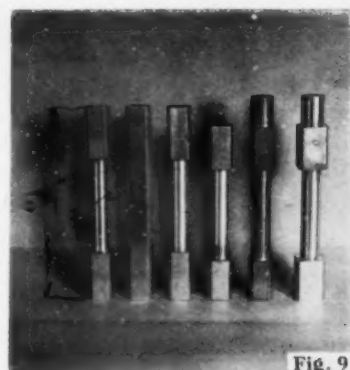


Fig. 9

this set-up represents one of the most sensitive measuring devices at our disposal in the present testing technique of materials.

### Specimens and Materials Tested

The dimensions and shape of the torsion specimens used for this investigation are shown in Fig. 9. The influence of the fillets, at both ends of the specimen as well as at their diameter, on the test results was investigated before adopting their final dimensions. The gauge length of the specimens was  $2\frac{1}{2}$  in. and their diameter  $\frac{7}{16}$  in. The radius of the fillets on both ends was practically zero, and the overall length, with two squares on each end ( $\frac{1}{2} \times \frac{1}{2} \times 1$  in.), was  $5\frac{1}{2}$  in. Altogether about 120 specimens were machined for this investigation. Several specimens for preliminary tests were supported, on one end of the lever by a square as well as by a bearing on a short cylindrical part. Later on, the support of the specimen by one bearing only was abandoned and, as may be seen by Fig. 1, an independent axis R supported by two roller bearings B-B', having the lever E fixed between these elements to avoid any detrimental bending of the specimen, was adopted. The specimen was fixed in a square hole of this axis by means of the two transverse screws V-V' (Figs. 1 and 5).

*To be continued.*

### The Nickel Bulletin

THE December issue of The Nickel Bulletin completes Volume 21, 1948. This issue contains the complete index of subject matter for the year, published under the headings of Subject, Author and Patents. Abstracts cover applications of nickel-containing materials in reference to chemical and railway engineering, the electrical, petroleum and motor industries, paper mills, sewage plants, among other subjects.

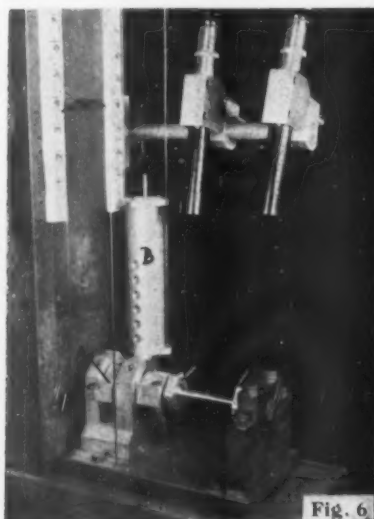


Fig. 6

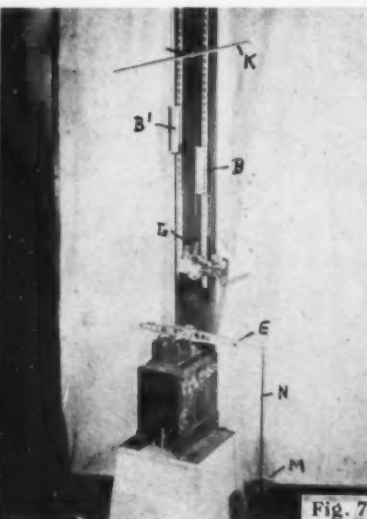


Fig. 7



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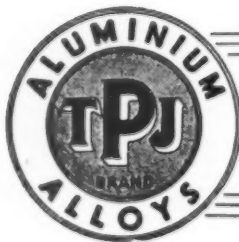


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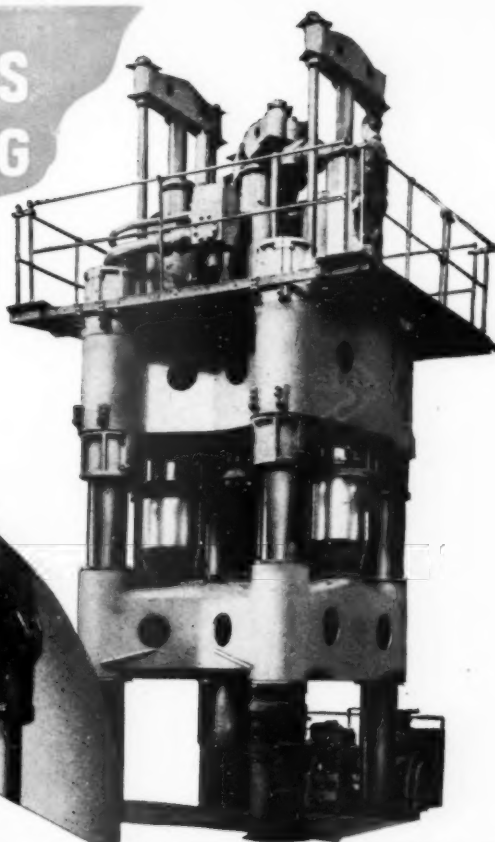
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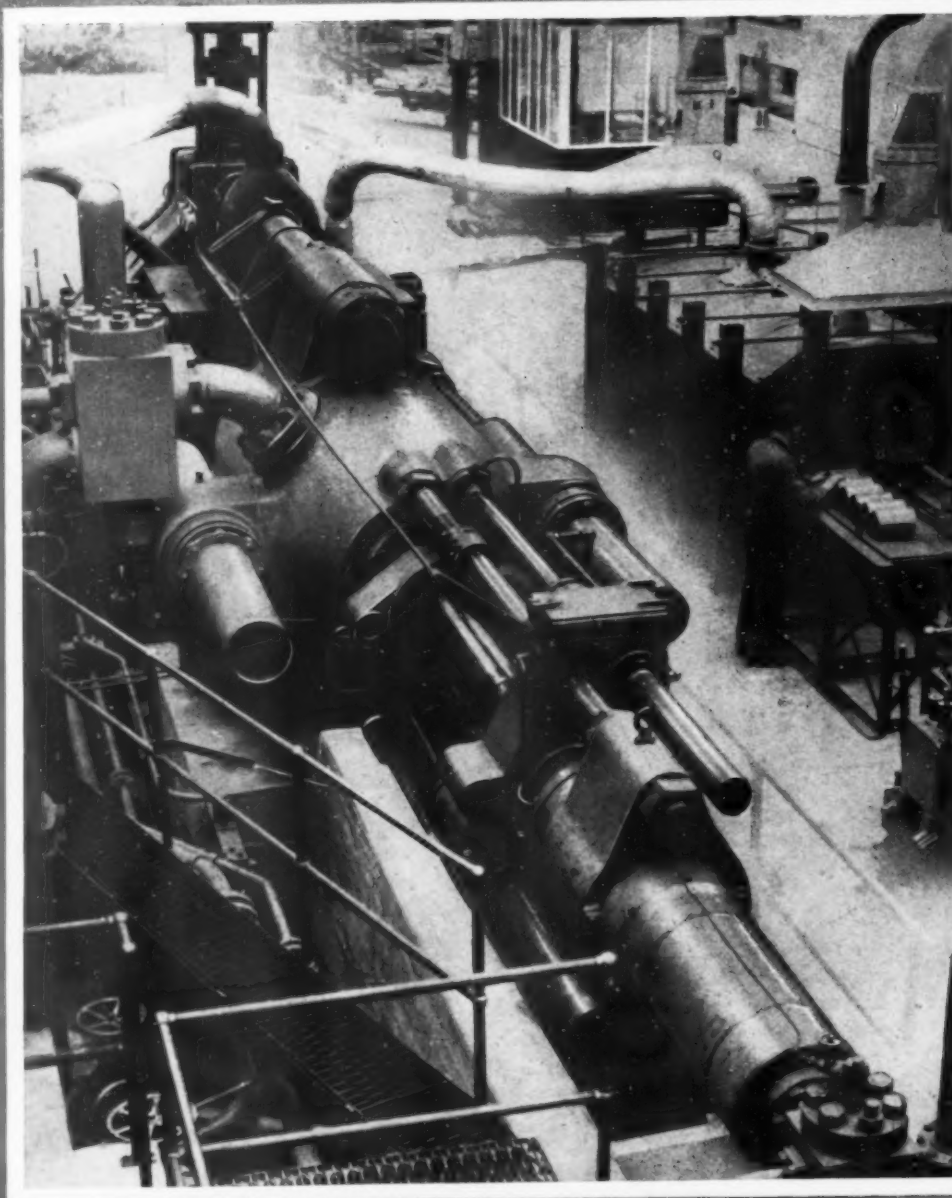


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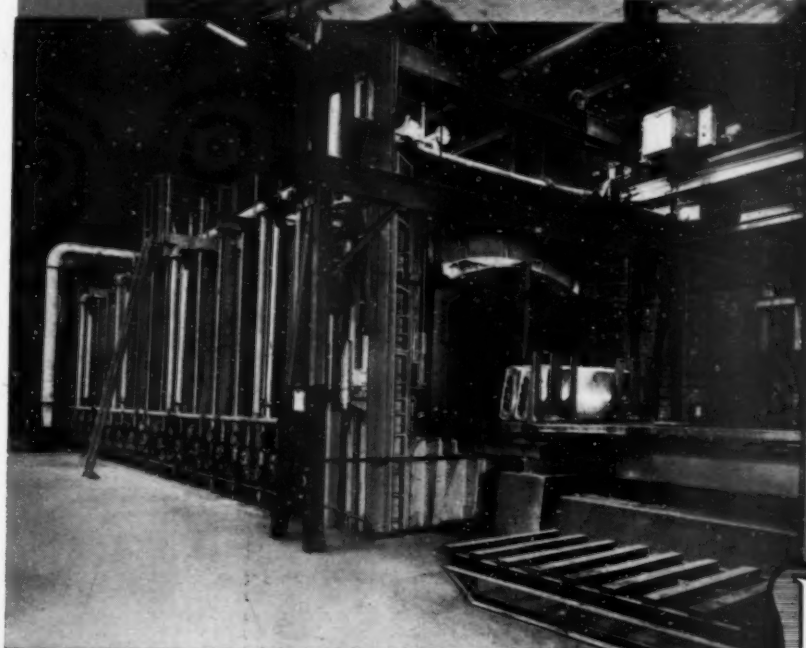








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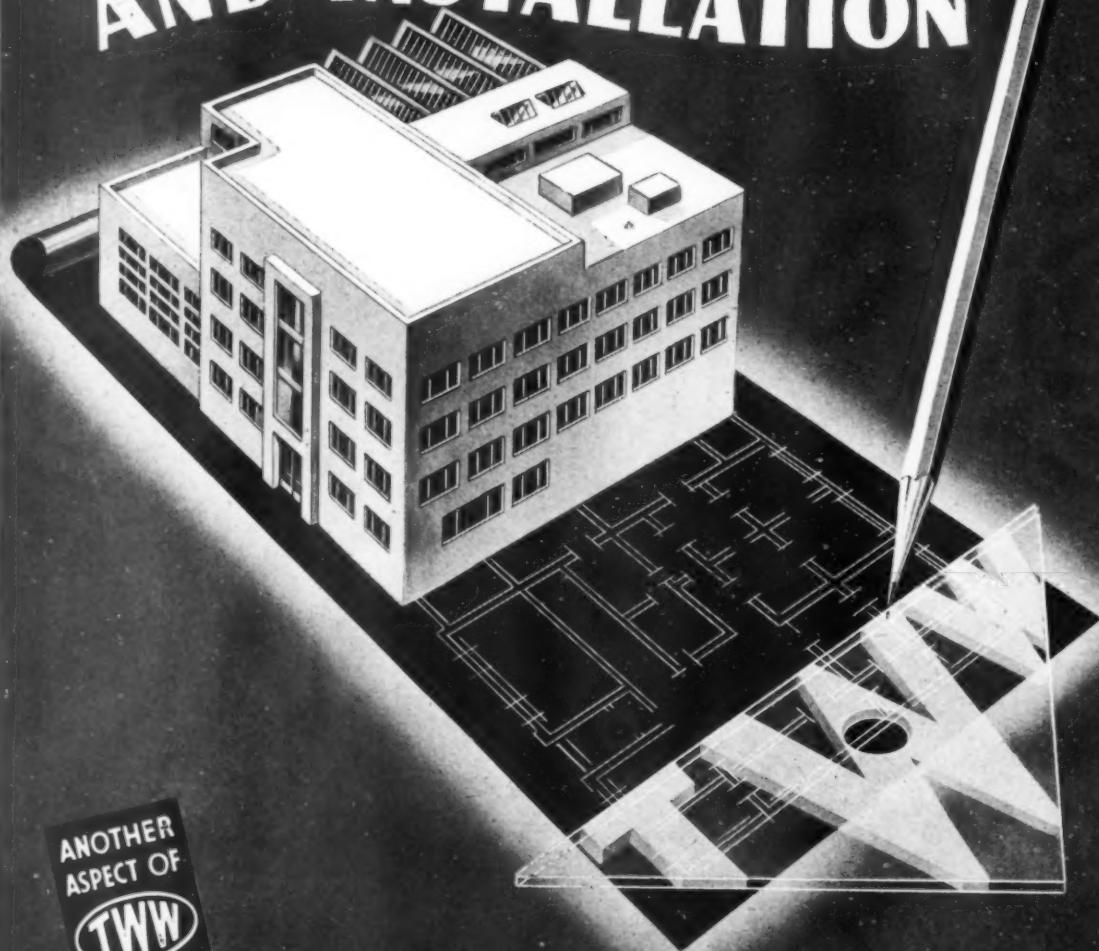
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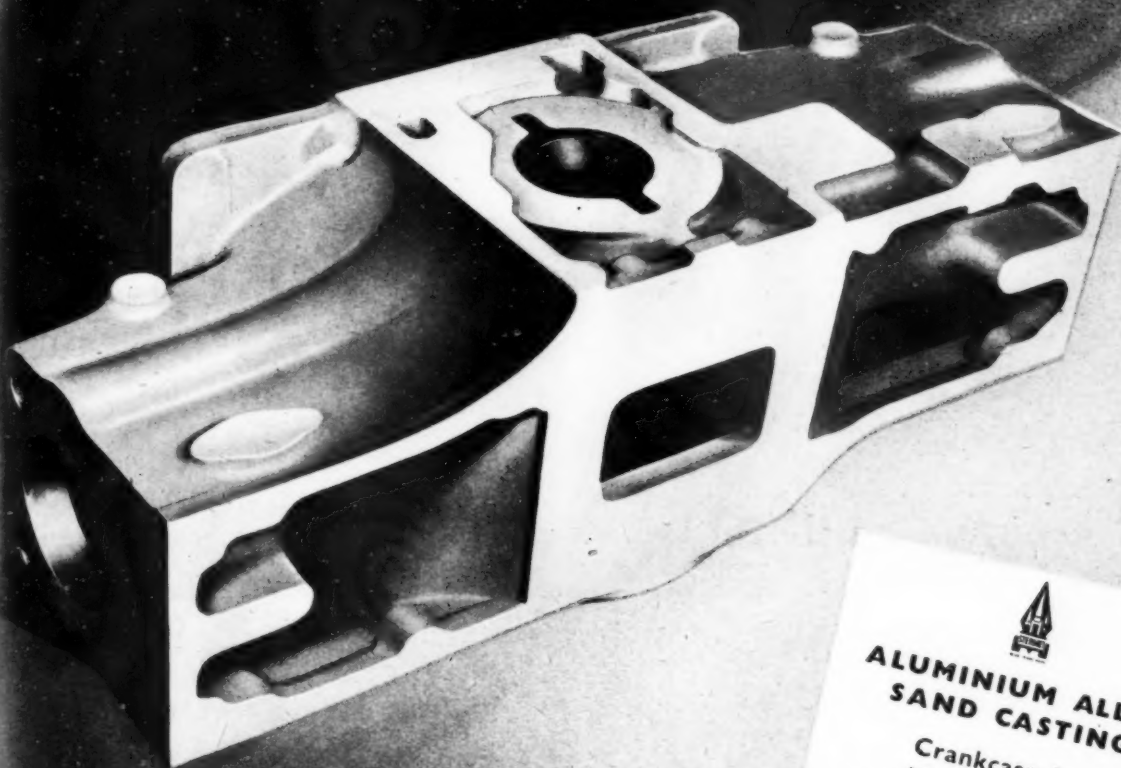
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# Design for Forging

## Application to High Strength Aluminium Alloys

*Only co-operation between designer and metallurgist can enable the fullest use to be made of the new alloys and specialised techniques developed for high strength aluminium alloy forgings. Some of the considerations involved in the production of such forgings are here discussed\* and reference is made to the mechanical properties of the forgings themselves as distinct from the properties obtained on separately forged test bars. Attention is also directed to close-to-form stampings.*

THE development of high strength aluminium alloys suitable for the production of highly stressed components by die forging is proceeding steadily to keep pace with the increased demand of aircraft designers. The original alloys, "Y" alloy and duralumin, which were introduced just prior to the first World War, owed their development to a rapidly expanding aircraft industry. Since that time, as greater and greater performance has been required of these components, the original duralumin has been developed into the present high strength material D.T.D. 364B ("Hiduminium" 66, Duralumin S and Noral 26 ST). In addition, research on a basically different alloy system has led to the introduction of the forging alloy D.T.D. 683 ("Hiduminium R.R.77, Duralumin L and Noral M 75ST"). This latter material possesses the highest mechanical properties of the known aluminium base forging alloys, and it is from its use that the advantages of high strength components largely derive.

As representative examples of material to these two specifications, R.R.77 and "Hiduminium" 66, although basically dissimilar in composition, achieve their maximum mechanical properties by careful working and subsequent heat treatment, as is largely the case in all aluminium alloy forgings. "Hiduminium" 66 has a composition which falls within the range:—

| Cu %    | Ni %      | Mg %    | Si %     | Fe %     | Mn %      | Al        |
|---------|-----------|---------|----------|----------|-----------|-----------|
| 1.1-1.5 | 0.15 max. | 0.4-0.6 | 0.75-1.0 | 0.6 max. | 0.65-0.85 | Remainder |

The normal heat treatment for the material is to solution treat for 4 hours at 510° C., quench into water at 70° C., and age-harden for 7 hours at 185° C. Forgings given this treatment will develop minimum properties in a longitudinal direction of:—

| U.T.S.<br>Tons/sq. in. | Yield Point†<br>Tons/sq. in. | Elongation %<br>(2 in. gauge length) |
|------------------------|------------------------------|--------------------------------------|
| 29.0                   | 25.0                         | 6.0                                  |

R.R.77 has a chemical composition which falls in the range:—

| Cu %      | Ni %     | Mg %    | Fe %      | Si %      | Mn %    | Zn %    | Al        |
|-----------|----------|---------|-----------|-----------|---------|---------|-----------|
| 0.25-0.55 | 0.1 max. | 2.6-3.0 | 0.45 max. | 0.45 max. | 0.4-0.8 | 5.3-5.8 | Remainder |

Aluminium alloy forgings produced to the above composition and heat treated as follows—solution treat for 4 hours at 460° C., quench into water at 70° C., age for 15 hours at 135° C.—will develop minimum longitudinal mechanical properties of:—

| U.T.S.<br>Tons/sq. in. | Yield Point†<br>Tons/sq. in. | Elongation %<br>(2 in. gauge length) |
|------------------------|------------------------------|--------------------------------------|
| 31.0                   | 27.0                         | 8.0                                  |

The highest mechanical properties obtainable by forging are those developed in the material D.T.D.683

and because of this it is largely recommended that for heavy duty operations this material should normally be specified, although for certain applications D.T.D.364B provides a useful alternative material. The working properties of the two materials show certain similarities, although specialised forging techniques have been developed for the working of the zinc-containing material R.R.77 to take full advantage of its capabilities. In the heat treatment of the two alloys greater latitude is allowable in the heat treatment of R.R.77 as the 510° C. specified for the solution treatment of "Hiduminium" 66 is approaching rather closely to the liquidus temperature of the eutectic constituent.

### The Forging Process

The forging process consists of forming material to close dimensional shapes in an impression machined into steel dies. The process is normally carried out at temperatures high enough to give the maximum plasticity to the material, but low enough to avoid difficulties due to hot shortness where the material is susceptible to liquation of low melting point constituents. Stock material for the manufacture of forgings is largely in the form of cast ingot or of bar which has been extruded to the required cross sectional area after casting. Forgings produced from these two stock materials require different treatments to achieve the best results in finished components; the most advantageous forging sequences for each stock have been thoroughly investigated, and the requirements peculiar to each material are now understood.

In the case of the forgings produced directly from cast stock, as the billet has a homogeneous structure, the mechanical properties can be taken as being similar in all directions in the ingot. In the cast condition these properties are low and the improvements brought about by heat treatment are relatively small. Forging operations performed upon this stock at high temperature break down the crystal structure and as, in forging, work is only applied on one axis at any one time the mechanical properties in one plane are developed at the expense of others. In order to overcome this difficulty, it is necessary to perform a series of operations on the cast ingot working different axes alternately, so that in the finished dummy, for use in the closed die for stamping to finished form, the properties will be as nearly as possible uniform in all directions. The mechanical properties obtained depend primarily on the percentage reduction given to the cast ingot in this initial dummie operation, and the size of the billet must be carefully considered in relation to the size and shape of the dummy to give the greatest possible percentage reduction

\* From *Hawker Siddeley Review*, August, 1948.

† Where values for "yield point" are quoted it is implied that testing has been carried out on sub-standard test pieces taken from components. The value, approximating to 0.2% proof-stress, is determined autographically.

on all the planes. At this stage the component will very roughly have the contours of the finished stamping, and will fit the impression machined in the stamping dies whilst leaving enough excess material to fill bosses, etc., and form a minimum of flash on the die parting line.

Where forgings are manufactured from extruded stock, the basic material has well-developed mechanical properties along a plane parallel to the axis of extrusion, but very low properties at right angles to this axis. Here the open die forging must be designed to work the billet on the low property axis at the expense of the longitudinal axis, and to eliminate as far as possible the original fibrous structure of the extruded bar where this occurs at such a position in the finished component that the end grain of the bar might be exposed by machining.

This fibrous characteristic of extruded bar can be exploited by careful manipulation and co-operation between stamping designers and producers so that the continuous flow lines can be made to follow the contours of components. The advantages which can be obtained by careful application of this particular feature are most apparent in stressed flanges, bosses, etc., where grain structures most suitable for the withstanding of bending and other stresses can be developed.

In this connection, Fig. 2 shows the grain flow obtained in a stamping in R.R.77 and illustrates where the axis of the extruded bar has been correctly applied to give the most advantageous structure in protruding bosses. In cast material grain flow can be produced in surface areas which have large displacement in relation to the body of the material, and this can be utilised to ensure that fine webs and projections do not possess unsatisfactory crystal structure.

#### The Design and Production of Forgings

Although the high strength materials forge readily at temperatures in the range 420°–470° C., the disposition or irregular masses on the component is of great importance and it is particularly useful that close co-operation should be maintained with the manufacturers whilst the design of any particular component is proceeding. In this way the inherent difficulties in the forming of contours on stampings can be discussed and their location at undesirable positions in relation to the die parting line can be minimised. In stamping dies, where tolerances have to be maintained, it is necessary that if the die life is to be kept at a maximum and the component produced on an economical basis all fillet radii and sections in the stamping which necessitate large vertical or horizontal movement must be kept under careful consideration. It is found in the case of both "Hiduminium" 66 and R.R.77 that deformation by upsetting will proceed satisfactorily at the forging temperature but difficulties arise in the running of webs and small bosses when these are removed from the plane of upsetting either horizontally or vertically. It is in the discussion of the relative position of these projections that the contact between designer and metallurgist is of the utmost value, as small differences in the forging procedure designed for each component can mean valuable saving in cost due either to ease of production of dies, or the working life obtained through removal of deleterious influences.

The technique of die forging depends on two allied factors: (1) the shape of the dummy which is to be used in the stamping die, and (2) the design of the dies

themselves. If forging difficulties such as folds and laps are to be avoided, metal must be distributed in the dummy so that no surface plane is worked at the expense of underlying layers, and that no point exists where horizontal and vertical stresses are having a simultaneous effect upon the material. Correct lubrication of dies is of first importance in the control and elimination of these defects, and much time has been expended in developing lubricants of suitable composition to give satisfactory results at the high working temperatures required of them. The difficulties due to the formation of folds, laps, and other surface defects are emphasised by the fact that when forming aluminium alloys under drop stamping hammers, the process is essentially one of surface movement rather than bodily displacement of metal. Dummy and component designs must be closely related to the hammer weight so that the power available for deformation is sufficient readily to move the metal at the forging temperature without unduly stressing the stamping die surfaces. Hammers having tup weights of between 10 cwt. and 18 tons are in use.

Fig. 1 illustrates the open die forging of a large ingot of cast material which is being broken down to give a forging of high mechanical properties. The ingot is in the alloy R.R.77 and the figure shows the working of two faces after the ingot has been upset on the cast axis plane, the combination of these and similar forging operations being designed to give uniform mechanical properties. Fig. 3 shows a partly machined stamping in R.R.77 and serves to demonstrate the close-to-form dimensional tolerances which can be obtained by normal die forging and the provision of large fillet radii. These design factors need careful consideration before components are floated on a production basis and in normal production work it is usual for the stamping to be tried in experimental dies. These "first off" components are examined in the laboratory for the observation of the grain flow and the mechanical properties in the various planes. Any modifications to the die or manufacturing sequences required to improve either the mechanical properties or the grain flow, or which might have an influence on die life, are recommended at this stage, when the dies and processes are modified before the component goes into production.

#### Mechanical Properties of Forgings

The methods used for the development of the maximum mechanical properties of forgings have been discussed and their dependence upon the type of stock material has been illustrated. Forging methods are continuously being developed both to ensure that the larger components which are now being required can be satisfactorily produced from the large diameter ingots available from recent developments in continuous casting and at the same time forging operations giving ease of working and uniformity of properties are continuously being investigated. By this means it has been found possible to guarantee to designers certain minimum properties in the two materials "Hiduminium" 66 and R.R.77 with the assurance that by specialised manipulation these basic minima will be maintained in the two compositions. In the two materials under consideration these properties are:—

|                     |      | U.T.S.       | Yield Point† | Elongation %         |
|---------------------|------|--------------|--------------|----------------------|
|                     |      | Tons/sq. in. | Tons/sq. in. | (2 in. gauge length) |
| "Hiduminium" R.R.77 | L .. | 31.0         | 27.0         | 8.0                  |
|                     | T .. | 29.0         | 25.0         | 4.0                  |
| "Hiduminium" 66     | L .. | 29.0         | 25.0         | 6.0                  |
|                     | T .. | 26.0         | 23.0         | 4.0                  |

L and T refer to longitudinal and transverse test pieces respectively.



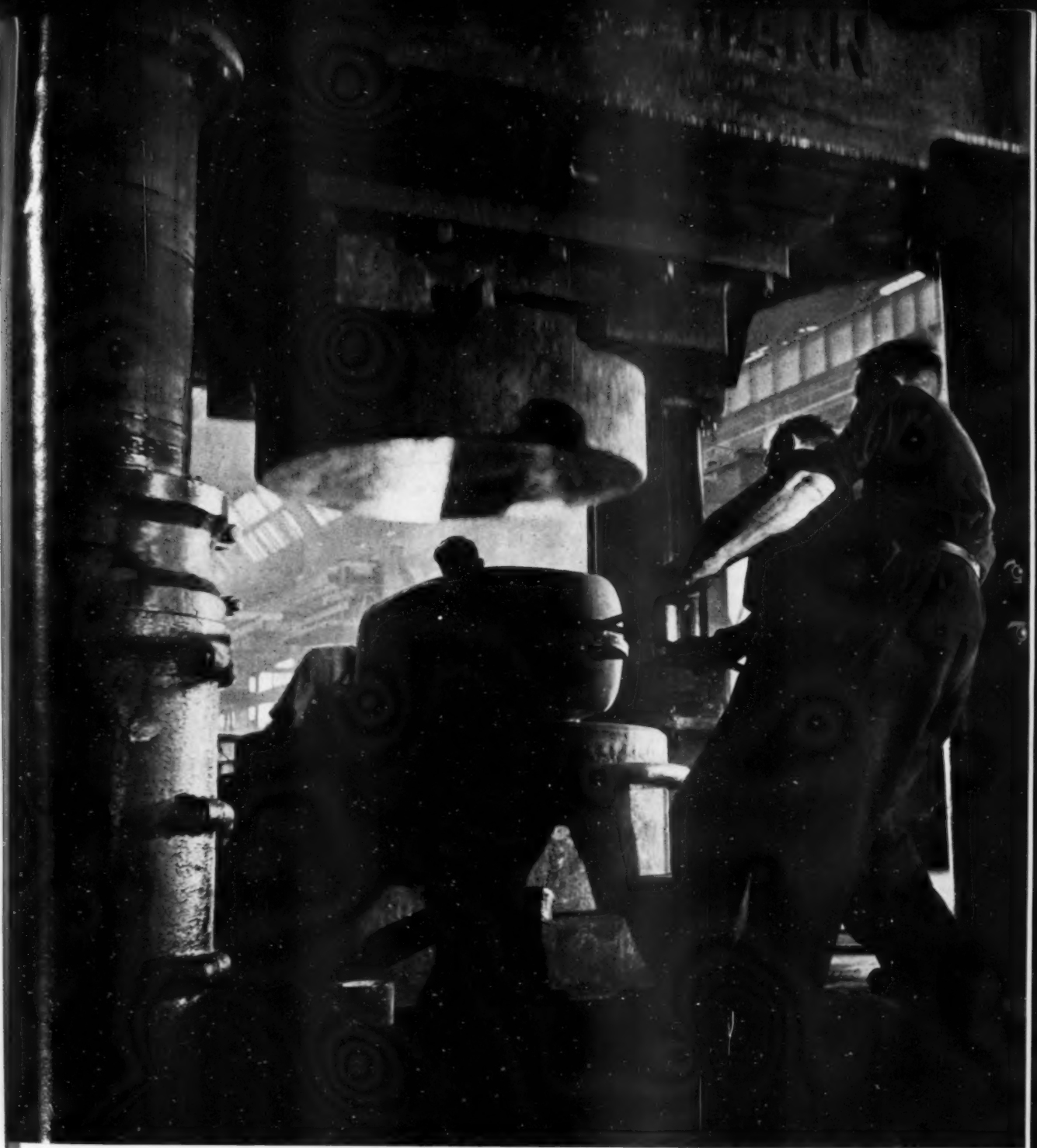


Fig. 1.—Open die forging of a large ingot of cast material which is being broken down to give a forging of high mechanical properties.

Normally these properties will be easily obtainable in the majority of forgings, particularly with R.R.77, and as experience is obtained and investigations completed a continuous improvement in these basic properties is being realised.

This system of guarantee of mechanical properties which will be obtained in components themselves is a useful advance on the previous system in which components were released subject to the mechanical properties obtained on test bars of the same composition



Fig. 2.— Grain flow obtained in a "Hiduminium" R.R.77 stamping.

as the forging, but forged separately. In the case of test bars, the metal is in the best possible condition having received the necessary amount of work to develop the maximum mechanical properties, so that no direct comparison between the properties of the test bar and the properties in all directions in forgings can be made. The test bar system has proved of great use in controlling both composition of metal and response to heat treatment. Now that the requirements of high strength forgings have advanced to a stage when designers require basic minimum properties in the forgings themselves, the test bar system requires amplification. With this in view the basic minimum properties which will be obtained by specialised forging processes for high strength components have been investigated in frequency curves covering a large number of components, so that it is now possible to give designers this basic information.

#### Close-to-Form Stampings

The tolerances to which die forgings can be produced have steadily improved as experience has been gained in the processes over the past few years, so that now stampings of certain types can be produced within very close limits. The advent of the gas turbine engine and the subsequent demand for compressor blades in light alloy necessitated the production of components by the forging processes which had dimensional tolerances previously considered to be impracticable. A surface condition too was demanded with such a degree of finish that stamped components could be inserted in compressor stages with a minimum of hand work after forging.

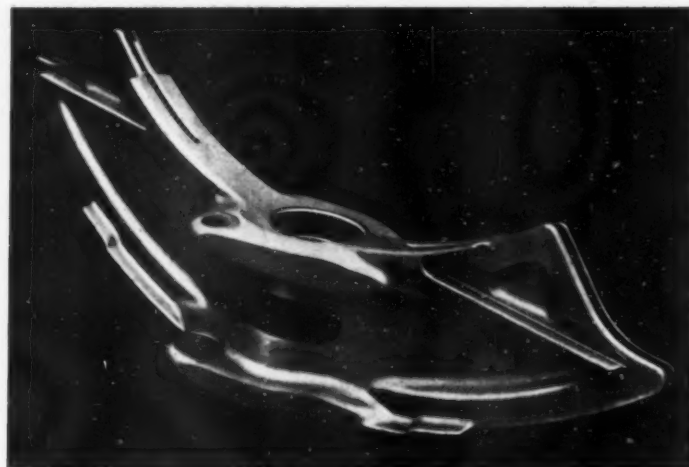


Fig. 3.—Stamping for a spar frame, in "Hiduminium" R.R. 77. The finished weight is 74 lb. and overall length 43 in.

For these components, "Hiduminium" R.R.57, with its high mechanical properties at elevated temperatures and its resistance to intercrystalline corrosion, was developed. This material has a composition falling in the range:—

|         |          |          |         |          |
|---------|----------|----------|---------|----------|
| Cu %    | Si %     | Fe %     | Mn %    | Ti %     |
| 5.7-6.3 | 0.2 max. | 0.3 max. | 0.2-0.3 | 0.1-0.15 |

After solution treatment at 530° C., quenching in water, and age-hardening at 215° C., it will develop minimum mechanical properties of:—

|                                |   |   |
|--------------------------------|---|---|
| U.T.S.<br>Tons/sq. in.<br>25.0 | 0.1% Proof Stress<br>Tons/sq. in.<br>11.5 | Elongation %<br>(2 in. gauge length)<br>8.0 |
|--------------------------------|---|---|

The aim in the production of compressor blades for gas turbine applications in light alloy was to manufacture stampings so close to form that they could be inserted in the compressor without hand work. The achievement of these requirements necessitated a completely new approach to the problems inherent in the forging operation, and the ultimate success of the processes depended on the closer synchronisation of moulding dies and the controlling of dummy weight so that no excess material was available at points of rapid change in section where small surface laps might otherwise occur. The surface condition necessary in the stamping to ensure a perfect section with no points from which fatigue can develop or eddy currents be set up in the air stream was of a very high order. This surface condition was finally achieved by scrupulous attention to the cleanliness of stamping die surfaces, the application of new lubricants and individual treatment of each component during processing. The production of close-to-form components with a high surface quality has therefore been developed to the stage where it is applied under production conditions.

#### Science and the Steel Foundry Industry

In discussing core bonding materials under the above heading in the last issue "Tufra-red-heating," referred to in the third paragraph of the second column of page 145, should read "Infra-red heating."

# The Use of Aluminium Alloys in Building\*

By E. I. Brimelow, M. Eng., A.I.M., A.I.Mech. E.†

*Reference is made to the advent of aluminium and its alloys as building materials and to the rapid growth of the aluminium industry. Differences between the physical properties of aluminium alloys and of steel are discussed in relation to the structural and architectural use of these materials. Mention is made of the use of aluminium in housing and for prefabricated unit construction. Factors governing the selection of aluminium alloys for building purposes, such as durability, are also discussed. The increasing use of aluminium for non-structural components of buildings is shown by reference to items such as window frames, rainwater goods, sinks and drainers, while the need for care in selecting fields of use, and the desirability of further research is stressed by reference to the failure of aluminium water pipes in service.*

## Advent of Aluminium

THE structural use of metals and indeed the dependence of engineering in general on the use of metals, is of quite recent origin. Desch<sup>1</sup> in his introductory Cantor lectures to the Royal Society of Arts in 1940 gave an historical account of developments leading to the use of metals as engineering materials.

Early use of metals in building was for decorative rather than for structural purposes and excavated statuettes and temple objects in copper or bronze, some dating as far back as 3,500 to 3,000 B.C., reveal the skill achieved in working these metals. Among the non-ferrous metals the use of lead dates back before the Christian era, and in the Science Museum, South Kensington, London, are exhibits of lead water pipes used by the Romans and of the type known to have been manufactured from the 1st century B.C.

The Chinese, about 300 B.C. had learned the art of making castings in iron and the store of iron ingots found in the palace of Sargon at Khorsabad date from the 8th century B.C., but there is no evidence of their structural use in those days. Difficulties in handling, working and welding large masses of metal no doubt account for this, and it was early in the 18th century before cast iron was used structurally in this country.

Against this historical background, aluminium and its alloys make a unique entry into the field of building materials for both structural and non-structural applications. A child of research and a comparative newcomer among metals it has, mainly as a result of scientific work done in the last sixty years, achieved a status among engineering materials comparable with older metals and alloys. The first few grains of aluminium were isolated by the Danish physicist, Oersted in 1825. In September, 1947, an all aluminium span of the Massena, N.Y. railway bridge was erected. This complete 100-ft. span weighed only 24 tons as compared with 57 tons for each of the three similar steel spans of this bridge. It is interesting to compare these weights with the weight of 378 tons for the first cast-iron bridge, also of 100-ft. span, built in 1797 by Abraham Darby, over the river Severn at Coalbrookdale.

## Aluminium Industry and Present-day Production

The achievement of so much in so short a time is largely due to the rapid growth of the aluminium industry. Based on a successful partnership between science and industry this vigorous new enterprise has expanded from a world production of about 100 tons per year in 1890 to a present production of over 1 million tons per year.

Since 1938 the aluminium fabricating industry of this country, closely linked with an expanding aircraft industry, has increased five-fold. With a total war-time capacity of about 350,000 tons of aluminium semi-manufactures a year (equivalent in volume to a million tons of steel) this country has risen from fifth to second place among the world's light-metal fabricators. This increase in production has been accompanied by a gradual reduction in price from £12 per lb. in 1855, the price of aluminium exhibited at the Paris exhibition in that year, to just over 8d. per lb. to-day. This reduction in price of aluminium and its alloys has been a major factor in the wider application of this material in building. In this connection it should be noted that aluminium is unique among materials of construction in that its price is lower than it was before the war and on account of the rise in the price of other materials, is now the cheapest of the non-ferrous metals per unit volume.

Although aluminium and magnesium are two of the most abundant elements, forming 10% by weight of the earth's crust, the question of future supplies of raw materials is of vital concern to the industry since its extraction as pure metal depends on large sources of supply of electrical power. With our stocks of virgin aluminium considerably reduced and the amount of scrap available for remelting very much depleted, it will be essential if we are to maintain our production of fabricated metal, to import most of the aluminium required for remelting, since we can only rely upon a home supply of 30,000 tons per annum of virgin aluminium.

The change-over from war to peace-time production has been carefully analysed by Devereux.<sup>2</sup> Although the total production of semi-manufactures in the United Kingdom for the first quarter of 1948 was 30% lower than for the same quarter of 1944 (when the war-time

\* Paper read before the British Association for the Advancement of Science, Sept 14th, 1948.

† Chief Scientific Adviser's Division, Ministry of Works.

1 C. H. Desch, "Metals as Engineering Materials," *J. Roy. Soc., A.*, 1940, 88, 591.

2 W. C. Devereux, *Light Metals*, 1948, 11 (125), 306.



Erection of the aluminium bungalow.

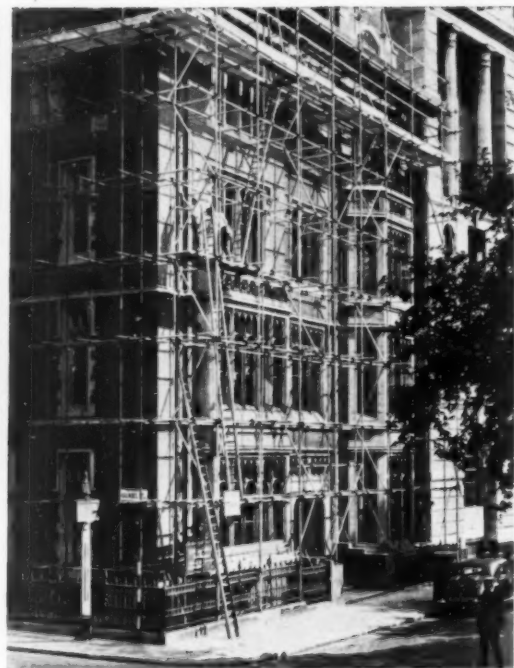
peak production was achieved) there have been corresponding increases in certain fields of products—e.g., sheet and strip 14%, foil 60%, gravity die-castings 17½% and pressure die-castings 117%. Comparative figures for extrusions, however, showed a decrease of 60%. These figures reveal the trend in peacetime application and in particular the high demand for sheet material has been due, to a large extent, to the increased use of aluminium cladding for such items as the aluminium house. The fall in percentage output of extrusions on the other hand would indicate that the demand for extruded structural members for building and other applications has not been sufficient to satisfy the available production capacity.

Shortages of materials such as cast iron, steel, lead and timber have in post-war years created large demands for alternative building materials. These conditions have been favourable to the wider application of aluminium and its alloys, and it will be shown later how far it has been possible to satisfy these new demands.

#### Structural Use

Details of the mechanical properties of aluminium alloys, with special reference to their use in structures, have been given in papers by Forrest and Smith<sup>3</sup> and by Hardy and Watson<sup>4</sup> to the Institution of Structural Engineers, and it is proposed now to refer only to certain important features of this subject, in so far as they have influenced the use of these materials in building.

Metallurgical research to meet the demands of the aircraft industry for high-strength aluminium alloys has resulted in recent years in the development of new alloys such as those covered by Specification BS.STA.7/AW16A which has a minimum ultimate tensile strength value of 35–38 tons/sq. in., 0.1% proof stress of 30–33 tons/sq. in., and an elongation value of 5%. Corresponding values for mild steel used for structural purposes are ultimate tensile strength 26–32 tons/sq. in. yield-strength 15–18 tons/sq. in., and an elongation of



Courtesy of Northern Aluminium Co., Ltd. and Messrs. Acrom (Engineers), Ltd.

Aluminium alloy scaffolding.

20%. Tensile strength, however, is not the only criterion in assessing a metal for structural purposes and, for many applications, alloys with lower strength properties would be useful, provided they satisfied other requirements such as good resistance to corrosion. The strength and stiffness of a structure cannot be calculated simply from the strength of its component members. Shear strength or bearing strength, depending on whether riveted or pin joints are used, may be just as important. In addition, the behaviour of a structure under compression is very different from its behaviour under tension. In the former, the slenderness ratio or buckling factor becomes very important in the design of struts and columns.

Aluminium alloys have a modulus of elasticity varying between 10 and  $10.8 \times 10^6$  lb./sq. in. for extruded material and is about one-third the corresponding value for mild steel. This value for Young's modulus cannot be altered appreciably by alloying (the highest value is  $11.8 \times 10^6$  lb./sq. in. for certain wrought aluminium-silicon alloys) nor by heat-treatment, and bears no relationship to the ultimate tensile strength. Because of the lower value of this constant, aluminium beams of deeper section compared with steel must be used if the same deflection characteristics as the steel beams are to be obtained. An aluminium alloy beam of similar shape to a steel beam, will be about one-third of the weight of the latter for equal strength. To obtain equal deflections, the moment of inertia of the aluminium beam has to be increased, and this may be accomplished by increasing the depth to 1.4 times the depth of the steel beam and increasing the flange area by 50%. The weight would then be about 50% of the steel beam. The requisite moment of inertia could also be obtained without increasing the flange area if the depth of the beam

<sup>3</sup> G. Forrest and F. R. C. Smith, "Aluminium Alloys, Their Properties and some of their Applications to Structures," Paper to the Cheshire Branch of the Inst. Struct. Eng. (1947).

<sup>4</sup> H. K. Hardy and C. G. Watson, "Aluminium Alloys and their Structural Use," *J. Inst. Struct. Eng.*, 1946, 24 (2).



were increased to approximately 1.7 times the depth of the steel beam. From the structural point of view the lower modulus of elasticity for aluminium as compared with steel, is an important difference between the two materials and for load-bearing members such as beams, it will be necessary to redesign steel sections for the use of aluminium in such a way as to achieve the desired structural characteristics in the most economical way. On the other hand an aluminium-alloy structure will have a greater degree of resilience on account of its low elastic modulus, and this is advantageous because of the greater ability of the structure to withstand impact stress and results in the reduction of secondary stresses in stiff-jointed structures.

Work by Baker and his co-workers at Cambridge into the behaviour of structures when deliberately over-loaded through the plastic range of stress to failure has yielded valuable information on such questions as allowable working stresses, factors of safety, importance of ductility and of the value of the ratio proof stress to ultimate tensile strength. The results of this work<sup>5</sup> would indicate that under static loading conditions there is no need to allow a higher factor of safety because of the lower values of ductility and high proof-stress to ultimate stress-ratio. Forrest<sup>3</sup> has, however, suggested that in structures subjected to fluctuating loads or vibration such as bridges where fatigue is a possible mode of failure, precautions are necessary because the implications are that with high yield-strength materials, secondary stresses over a considerable part of the structure will be higher, relative to the fatigue properties of the material, than would be the case with a low yield material. The simple precaution of providing gussets and cover plates in an alloy with a relatively low yield strength should enable one to guard against failure.

As far as possible, without limiting the scope of the designer, it is desirable for purposes of economy and ease of production, to standardise aluminium alloy structural sections, and a British Standard Specification (B.S.1161: 1944) has been published,<sup>6</sup> which gives dimensions and tolerances for standard extruded sections.

#### Architectural Use

In choosing a material for a building or structure it is not sufficient that it should possess the desirable physical properties, but certain aesthetic aspects which affect the design of the building must also be taken into account.<sup>7</sup>

The influence of materials on architecture has been recognised. The introduction of new materials such as steel, concrete and aluminium, provide from the architectural point of view a certain amount of flexibility in planning. The use of stressed members in the form of frame construction has tended to replace the solid load-bearing wall and enables a freer use of walls and partitions. Large openings or windows in walls are made possible



*Courtesy of The Bristol Aeroplane Co. (Housing), Ltd. and Northern Aluminium Co., Ltd.*  
Warehouse construction, 3-bay  $\times$  490 ft.  $\times$  40 ft., showing aluminium alloy stanchions, beams and trusses.

and "straight line" architecture can be broken down by projecting canopies, cantilevered floors and recesses. Additional scope is also provided in roof design, since large spaces can be covered easily and economically. With the additional quality of light weight (sp. gr. of aluminium 2.6-2.8, compared with 7.8 for steel, 8.8 for copper and 11.4 for lead) aluminium would materially assist this modern trend in architectural planning. It is for applications such as roof trusses of large buildings, arches of wide span and bridges, where the chief factors in the economical use of aluminium is light weight, ease of transport and reduction in erection time, that aluminium alloys are most attractive.

#### Use in Housing

In the design and production of the aluminium house or aluminium "temporary" bungalow we have a unique example of the adoption of a new material to meet emergency building requirements. The production and erection by May, 1948, of 54,000 of these houses has demonstrated the useful possibilities of prefabricated aluminium structures and has been the means of establishing a new industry in this country.

In each of these houses, about 1½ tons of aluminium in the form of sheet, strip, extrusion and castings were used, and it has been stated that this programme has taken about 40% of the industries sheet, strip and extrusion capacity. For the extruded members a secondary alloy, covered by specification D.T.D. 479 was used, which in the heat-treated condition gave a minimum ultimate tensile strength value of 22 tons/sq. in., 0.1% proof-stress of 14 tons/sq. in., and an elongation of 8%. The sheet material 20 or 22 S.W.G. had a core of material to specification D.T.D. 479 clad with aluminium of minimum 99% purity for additional protection against corrosion. An interesting feature of the construction was the casting of a foamed cement infill into wall and partition panels formed from extruded sections and rolled strip riveted together. The filling used was carefully selected to give adequate sound and thermal insulation. The panels were sprayed internally with hot bitumen before filling and the panels subjected

<sup>5</sup> J. F. Baker and J. W. Roderick, "Investigation into the behaviour of welded rigid frame structure." *Trans. Inst. Welding*, 1938, 1 (4), 1940, 5 (2) and 1942, 5 (3).

<sup>6</sup> Aluminium Alloy Sections, B.S. 1161: 1944, British Standards Institution, London.

<sup>7</sup> The Architectural Use of Building Materials — Post-War Building Study, No. 18, London, 1946, H. M. Stationery Office.

to steam curing and hot-air drying. Investigations to date have shown the aluminium bungalow to be an efficient dwelling and the Ministry of Health, in agreement with local authorities, has ordered 15,000 "permanent" aluminium houses similar to the "temporary" buildings, but with certain slight modifications to improve thermal insulation and to minimise the risk of condensation.

Interesting developments in aluminium buildings as a result of the experience gained with the aluminium house are seen in prototype school buildings based on prefabricated unit construction and aluminium bungalows for use in the tropics, where, in addition to ease of transportation, resistance to attack by insects and dimensional stability in that it does not rot, warp nor swell are additional advantages of aluminium construction. Industrial projects are also in hand for two-storey houses, using factory-built wall, floor, roof and ceiling units, and for multi-storey buildings, employing a prestressed, pre-cast concrete frame and factory-built wall, floor and partition panels. These new designs aim at conserving the use of traditional building materials such as timber and steel, while keeping total erection and building costs competitive with traditional types of buildings.

### Roof Construction

Aluminium as a roofing material has not competed, until recent years, with lead, zinc, copper and galvanised iron to any appreciable extent in this country. Actual service experience<sup>8</sup> in America, Switzerland, Germany, Italy, and Australia during the last 50 years has confirmed that this material, with its light weight, adequate strength, good resistance to atmospheric corrosion, and versatility of form is a very suitable roofing material. The low emissivity or high reflectivity value of the polished surface of sheet aluminium also gives good thermal insulation properties.

Provided suitable aluminium alloys such as those covered by B.S./STA.7/A.W.3C (an aluminium alloy containing 1.0-1.5% of manganese) or B.S./STA.7/A.W.15G (aluminium-clad alloy) are chosen for roof sheeting, a satisfactory service life can be expected under normal atmospheric conditions, even without painting. Under severe conditions of service, such as in a marine atmosphere, or in a heavily-polluted industrial atmosphere, a protective coating of paint would be advisable.

In view of the shortage of timber, several designs of roof trusses are under consideration. The roof of the aluminium house referred to above was formed of two trusses and two trussed purlins constructed of extruded or rolled sections bolted to the walls and spine partitions and covered with aluminium-alloy panels 2 ft. 6 in. wide, each panel being faced internally with a layer of sheet insulation. Suitable alloys for these extruded sections include B.S./STA.7/A.W.10B, which, although not one of the high-strength alloys, has in the fully heat-treated condition a minimum ultimate tensile strength of 18 tons/sq. in., 0.1% proof-stress of 15 tons/sq. in. and 10% elongation. High-strength alloys such as B.S./STA.7/A.W.15B have also been used, but on account of their lower corrosion resistance require painting and regular maintenance.

In aluminium roof construction, however, precautions must be taken against electrolytic corrosion, by careful

choice of nail and rivet materials, by avoiding copper fittings, and by galvanising or cadmium coating all iron and steel nuts, bolts and similar fittings in contact with the aluminium. Allowance has also to be made, in the case of large roof spans, for thermal expansion. The coefficient of thermal expansion of aluminium varying between  $22 \times 10^{-6}$  per °C., as compared with  $17 \times 10^{-6}$  per °C. for copper,  $26 \times 10^{-6}$  per °C. for zinc,  $29 \times 10^{-6}$  for lead, and  $12 \times 10^{-6}$  per °C. for iron and steel, is approximately twice that of steel. However, with Young's Modulus only about one-third that of steel, temperature stresses induced in an aluminium structure for a given rise in temperature will be slightly less than two-thirds of those in a similar steel structure.

An interesting application, still in the experimental stage is that of roofs supported by air pressure, for long span building construction<sup>9</sup>. Tests made at New York University in 1944 indicated that enormous roof spans could be made with the minimum of structural materials. Structures ranging from 300-1,800 ft. diameter for storage warehouses, industrial and amusement buildings, where clear span and low cost were important factors, have been investigated. An 800-ft. diameter roof in aluminium sheet 0.109 in. thick was to be supported by an air pressure of 0.06 lb./sq. in.

### Selection of Alloy

Reference has already been made to suitable aluminium alloys used for specific building applications, but a few general comments on the selection of alloys, may be useful. Difficulty has often been experienced by those desiring to use aluminium alloys for the first time, in the selection of suitable alloys from the large numbers of proprietary alloys available. The position has been clarified to some extent; by the work of the British Standards Institution who have drawn up British Standards giving specific ranges of chemical composition and condition of material. Each of these specifications may be satisfied by a number of alloys with different proprietary names. This Institution has recently taken a further step forward by drafting, in collaboration with the industry, trade associations and government departments concerned, schedules for cast and wrought aluminium alloys for general engineering purposes. The primary purpose of these specifications is to ensure a reasonable standard of quality of material and they do not state which alloy is the best for a particular purpose.

Final choice of an alloy for a particular application depends, apart from economic considerations, on many factors, including method of manufacture such as, whether cast or wrought product, nature and extent of stresses, if any, to which component will be subjected in service, type of atmospheric or other corrosive conditions to which material may be subjected, and surface treatment such as anodic treatment or painting, or method of jointing such as welding, to be applied.

Secondary alloys made up from refined remelted scrap are available, and when they comply with approved specifications are satisfactory for many applications. These secondary alloys have, however, a higher impurity content than the primary alloys of the same type, and as a consequence, have a lower resistance to corrosion.

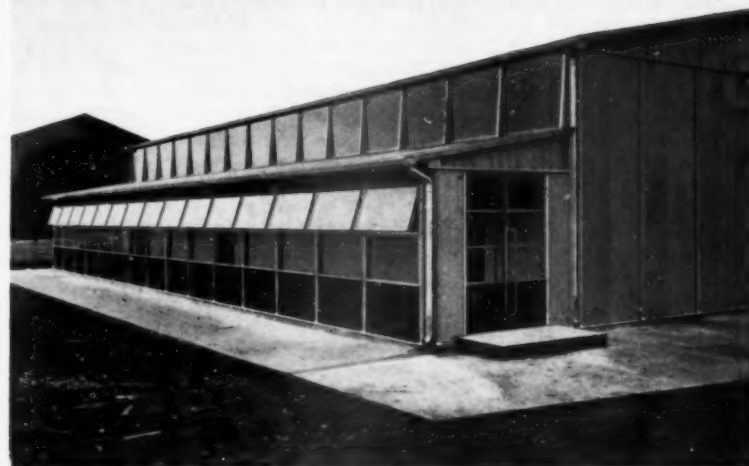
A convenient method of grouping aluminium alloys is according to their inherent corrosion resisting properties. Generally the high-strength copper-containing alloys which attain their tensile strength properties by heat-

<sup>8</sup> E. Muller, "Aluminium for Roofing," (A.L.A.G., Chippis, Switzerland), *Light Metals*, February, 1946.

<sup>9</sup> H. H. Stevens, "Roofs Supported by Air Pressure," *Nature*, 1946, 161 (4094).



*Courtesy of British Pressed Panels, Ltd.*



*Courtesy of the Bristol Aeroplane Co. (Housing), Ltd.*

**Prototype school building utilising aluminium unit construction.**

**Double-hung sash-type aluminium alloy window.**

treatment have the lowest resistance to corrosion. Alloys free from copper as an alloying addition and which, in the case of wrought alloys, rely upon definite amounts of cold work for their strength properties, have the best corrosion-resisting properties. This classification was adopted in the report of the Light Alloys Sub-Group of the Admiralty Chemical Advisory Panel, Group V (Metallurgy) on aluminium alloys for naval use.<sup>10</sup>

### **Durability**

The question of durability is frequently raised in discussions on the suitability of aluminium for buildings. Aluminium alloy sheet used in buildings has been known to fail within a few months of service when in direct contact with damp alkali-containing building materials such as cement and concrete and electro-chemical or electrolytic corrosion attack can occur under certain conditions when aluminium is in contact with iron, copper or even dissimilar aluminium alloys. The causes for these isolated cases of corrosion are well known and they can be avoided by taking suitable precautions such as by painting or by preventing direct metal contact with an insulating layer of impregnated fibre. Both laboratory and actual service experience have shown that aluminium and many of the aluminium alloys of the non-heat-treatable type available in sheet or extruded form have a greater resistance to corrosion than steel and cast iron, and compare favourably with zinc, lead and copper in marine or severe industrial atmospheres. The deterioration in surface appearance which occurs when these alloys are exposed to the atmosphere is due to very slight superficial corrosion and does not lead to

any appreciable deterioration in the strength of the material. With the higher strength alloys of the heat-treatable type, extra thickness of metal would be necessary to allow for the "pitting" type of corrosion attack which occurs on prolonged exposure under severe conditions, or additional protection provided by surface pre-treatment such as anodising and painting. An even more dangerous form of corrosion, to which all types of alloys, and heat-treatable alloys in particular are susceptible in the presence of certain corrosive media, is inter-crystalline corrosion which usually occurs when the material is subjected to internal or external stresses. The danger of this type of corrosive attack is that it may occur by localised penetration into the metal along the grain boundaries leading to loss in ductility and strength, without any visible signs of surface corrosion. Once again, however, risk of failure by this cause should not be exaggerated since the danger can be avoided during production by careful control of the thermal treatments given to the material.

As mentioned previously, aluminium like zinc and lead is attacked, in the presence of moisture, by contact with building materials such as concrete, cement, mortar and plaster which liberate lime on setting. Portland cement is most aggressive, but aluminous cements and slag cements which do not liberate lime on setting are less liable to cause trouble. The presence of calcium chloride in concrete added to accelerate hardening, or of free chloride in magnesium-oxychloride cements, often hygroscopic, is most dangerous. Aluminium should therefore, be protected from this type of attack by a thick coating of bituminous paint or by wrapping with bituminised paper or similar insulating material that is, impervious to moisture.

### **Painting**

When it is desirable to paint aluminium, either for purposes of additional protection because of the alloy selected for particular service conditions, or for aesthetic reasons, care is necessary in the preparation of the surface in order to obtain good adhesion. It is preferable, when it can possibly be arranged, to prepare the surface

<sup>10</sup> Aluminium Alloys for Naval Use — Report prepared by the Light Alloys Sub-Group of the Admiralty Chemical Advisory Panel, Group V, (Metallurgy), London, 1945, H.M. Stationery Office.



and apply at least the first or priming coat of paint at the manufacturers. Suitable processes for site preparation are, however, available when necessary. Anodising as carried out under specified conditions, provides one of the best surfaces for paint. It is not always practicable to apply this process to large or complicated surfaces, nor is it suitable for all aluminium alloys, but other suitable proprietary chemical processes can be used, details of which, together with the details of suitable paints, lacquers and enamels, have been published.<sup>11</sup>

### Fire Resistance

The relatively low melting point of aluminium and its alloys, 659° for pure aluminium, compared with structural steel with a melting point of about 1,350° C., has given rise to a certain amount of anxiety with regard to the fire risks involved in using aluminium structural members. In a fire, however, strength properties would begin to fall off rapidly at much lower temperatures. The yield-point of structural steel is 8 tons/sq. in. at 450° C., and if this stress is taken as the minimum working stress, then 450° C. may be regarded as a limiting temperature for a fully-loaded steel structure. The corresponding limiting temperature for aluminium alloys is of the order of 225° C., when the proof-strength will have fallen, in the case of high-strength alloys, from about 26 tons/sq. in. at room temperature to 11 tons/sq. in. It would, therefore, be necessary, in order to ensure a standard of fire-resistance comparable with that of a steel structure, to take additional precautions by surrounding aluminium stanchions with a thicker casing of concrete or envelope of insulating material. The higher thermal conductivity and specific heat in the case of aluminium may be additional factors governing the period of safety, but in the case of a fire within a building with a high output of heat, it is doubtful whether they would have a significant effect. The risks in the case of aluminium roof structures and roof coverings is not so great since the melting temperature is sufficiently high to avoid dangers from external sources and fire resistance is probably better than other roofing materials such as lead, zinc, and timber.

### Non-structural Uses

The versatility of form in which aluminium and its alloys can be produced in the form of castings, forgings, sheets or plates, as extruded, rolled or drawn sections and bars, and in the form of tubes or hollow sections, enables it to be used for the reproduction of artistic designs for many architectural purposes. Applications more often seen abroad than in this country, include railings, grills, spandrels, pilasters and cornices. Lightness, resistance to atmospheric corrosion and freedom from staining adjacent surfaces are favourable properties of aluminium for these applications.

An interesting example<sup>12</sup> of the large-scale use of cast aluminium spandrels is the Rockefeller Centre Group in New York, where 1,660 tons of aluminium cover 17% of the external surface. After ten years' service in a severe industrial atmosphere and without any maintenance, these spandrels are now indistinguishable from the stone wall owing to the collection of oxide and soot, but apart from this surface deterioration are in good condition. Four ornamental cast aluminium plaques

on these same buildings, which were enamelled in colours; although never cleaned, have withstood the weather as well as the 10-ton cast stainless-steel (24% chromium-12% nickel) bas-relief over one of the entrances.

We have now more than fifteen years' experience of aluminium window frames in this country, and this application has been extensively developed in America. Outstanding examples of this use are to be seen in the New University Library, Cambridge, and the Bodleian Library, Oxford. Provided suitable alloys are used and with improved methods of making welded joints it is considered that this application will be extended. The tendency for anodised frames to deteriorate in appearance can be avoided by washing the surface with water or wiping with a wax polish. These window frames would need appreciably less maintenance than similar steel components. The use of specially designed extruded sections and of hollow sections give considerable scope to the designer for achieving economies in material and installation costs, as well as for achieving a pleasing architectural appearance. Similar remarks apply to aluminium roof-glazing which has proved satisfactory under severe conditions of service.

Wide use is now being made of aluminium rainwater goods, which on account of their ease of installation, low breakage losses and satisfactory service to date, are proving a satisfactory alternative to the traditional cast iron components. Gutters, downpipes and fittings, cast or extruded are made to standard designs, dimensions and materials as specified in B.S. 1430 : 1947<sup>13</sup> and draft specifications covering rainwater goods made from sheet aluminium alloy are also being prepared. At present most of these rainwater goods are being made in secondary aluminium alloys which are not of the most corrosion resistant type and painting is strongly recommended for industrial and coastal areas.

Because of the urgent need to economise in the use of lead in building, aluminium or suitable aluminium alloys have been included among the suitable materials for such items as main roof covering (in alloys to B.S./STA. 7/- A1, A2, AW4C, AW15G), valley gutters (in alloys to B.S./STA. 7-AC2, AC6, AW4, AW9, AW10) flashings and soakers (in alloys to B.S./STA 7-A1, A2, A3, and A4D or AW3C) and for patent glazing (in alloys to B.S./STA. 7-AW3A, AW5A, AW9A, AW10A.) in addition to rainwater goods.

The thermal insulation of buildings has been given considerable attention<sup>14</sup> and for this purpose aluminium foil or foil covered paper has been used to a limited extent in house construction as a lining in wall cavities, under floors and in roofs. With a low emissivity value of about 0.05 compared with a value of about 0.9 for common building materials, bright clean foil in conjunction with an air space can be used for building a wall with a low thermal transmittance. Special care is necessary in fixing this foil to maintain the air spaces and to avoid accumulation of dust which would appreciably increase the emissivity value of the foil.

Aluminium scaffolding is now a familiar feature of building work in progress in London and other towns, although it is only about five years ago that this appli-

11 Surface Finishing of Aluminium and its Alloys — Information Bulletin, No. 13, 1947, The Aluminium Development Association, London.

12 Myron Weiss, "Maintenance of Metallic Trim at Rockefeller Centre," *Metal Progress*, 1947, 58 (5).

13 B.S. 1430 : 1947, Aluminium Rainwater Goods (Cast and Extruded), British Standards Institution, London.

14 G. B. Wilkes, F. G. Hechler and E. R. Queer, "Thermal Test Coefficients of Aluminium Insulation for Buildings, Heating and Piping," (*J.S.H.V.E. Journal Section*), 1940, 12 (1).



cation was seriously considered. The advantages of using aluminium alloy instead of steel scaffold tubes are already recognised. Because of the lightness of the aluminium tubes, erection time and transport costs may be reduced by as much as 50% and freedom from rusting makes them cleaner to handle and a longer service life can be expected. These advantages, together with a higher scrap value, offset their initial higher cost. Alloys such as those covered by specification B.S./STA. 7/AW. 10C. have been used and load tests made on scaffolding in this alloy have proved their suitability for all conditions of service, even when using tubing of the same dimensions as the conventional steel tube.<sup>15</sup>

Cast aluminium moulds have also been used extensively for making pre-cast concrete blocks used in building construction, and if suitable dressings are given to the mould, a good mould life is obtained without undue surface attack from the wet concrete.

Aluminium is now used in the form of sprayed coatings to protect iron and steel and even aluminium alloy structural components. Investigations to date indicate that for coatings of equal thickness, aluminium is equal to zinc as a protective coating and is probably superior under conditions of high humidity and pollutions.<sup>16</sup> As a constituent of paint aluminium has, of course, been used for many years, particularly as a finishing coat.

### Plumbing Applications

Experience with aluminium alloy water service pipe installations in France and the U.S.A. have confirmed the results of laboratory tests made in this country which showed that these installations are prone to a severe form of localised or "pitting" corrosion attack which rapidly perforates pipes used for hot and cold water services. This type of failure does not always occur and the performance of these installations has varied according to the district and nature of the water supply. A careful study of this problem has been made in France but as the report by M. Lafuma<sup>17</sup> has shown, it is not yet possible to account fully for the causes of this severe form of attack. It is therefore not advisable to use aluminium for water service pipes. On the other hand, gas pipe installations have given satisfactory service as have also aluminium radiators or convection heaters, when used in conjunction with iron or steel pipe. In the latter case a deposition of iron oxide or rust is usually found on the inside surface of the aluminium heater which appears to protect the aluminium from localised corrosion attack.

The possibilities of using soil pipes in aluminium alloys are being investigated, special attention being given to the development of suitable joints which must be gas tight as well as corrosion resistant. Cast aluminium water cisterns are also worthy of consideration but it would be advisable to protect at least the inside surface with a suitable lacquer or bituminous coating and to avoid copper fittings or copper pipes in the same circuit, which may cause electro-chemical corrosion.

Another application of aluminium is in the manufacture of flexible or pliable tubing, especially suitable for electrical wire conduiting. Aluminium strip and bituminous impregnated strip are fed into a specially designed machine which forms and ejects the tube

continuously. Because of the pliability of this type of tubing there is an appreciable reduction in the time of installation.

During the last two years, many local authorities have fitted aluminium sinks and drainers in their houses and recent surveys of their performance indicate that these components have given satisfactory service under normal household and canteen kitchen conditions. These components have been made as die-castings in aluminium-silicon types of alloy or fabricated from aluminium alloy sheet. Reports on their service performance have been published<sup>18,19</sup>, and the results of surveys made in many parts of the country would indicate that, in cases where the sinks and drainers were cleaned regularly, their performance under severe service conditions was satisfactory and actually their surface appearance improved with good use. While it is harder to keep these components clean in comparison with glazed earthenware sinks, this disadvantage is offset to a certain extent by having the sink and drainer in one unit, thus avoiding the leakages which occur between a separate sink and drainer. There is little evidence to date that severe staining is caused by fruit juices or that the use of ordinary alkaline washing solutions are harmful, while no troubles have been experienced at the outlet joints where precautions are taken, by using fibre washers as insulators, to avoid electrolytic attack.

### Conclusions

An endeavour has been made in this brief survey to indicate the most salient features in the present-day use of aluminium in buildings. Shortages of other building materials have, in post-war years, provided many opportunities for new applications but it is noteworthy that the use of aluminium has been carefully restricted to those fields where its use could be justified on technical grounds. The additional data concerning performance which will become available as a result of these new uses of aluminium will be very valuable when considering the suitability of these materials for more ambitious schemes in the future.

While there is a steady increase in the use of aluminium mostly in sheet form, the structural use of aluminium, except in the case of the aluminium house, has not been extensive and has usually been confined to special projects. This is not very surprising in view of the lack of design data for large frame and roof structures and the high price of aluminium structural members, which is about twice that of steel. There are, however, indications that this structural material will be more widely used in the future particularly where prefabricated or unit construction is contemplated for such buildings as schools or factories. For special buildings such as exhibition buildings where ease of transport and rapid erection time is essential, the advantages of aluminium are already recognised.

In other fields, such as naval architecture and bridge construction there is an increasing use of aluminium. New projects such as the twin-leaf trunnion bascule bridge constructed in aluminium alloy for the River Wear Commissioners, over the Hendon Dock Junction Gateway at Sunderland will no doubt be followed closely by all interested in the application of aluminium

<sup>15</sup> Scaffolding in Light Alloy — *Light Metals*, 1948, **11** (125).

<sup>16</sup> J. C. Hudson and T. A. Banfield, "The Protection of Iron and Steel by Metallic Coatings," *Journal Iron and Steel Institute*, 1948, **158**.

<sup>17</sup> H. Lafuma, Study of the Corrosion of Aluminium Pipes, *L'Institut Technique du Batiment et des Travaux Publics, Circulaire Serie G.*, No. 6, 1943.

<sup>18</sup> "Die-Cast Aluminium Sink — Record of a Year's Use," — *Light Metals*, 1947, **10** (115).

<sup>19</sup> Wrought Aluminium Sink," — *Light Metals*, 1947, **10** (117).

Meanwhile metallurgical research will continue to have an important influence on future developments and recent advances such as improved methods of welding and brazing aluminium, the development of high strength alloys with good corrosion resistance and capable of being welded, together with improved protective coatings will eventually result in a still wider application of aluminium base materials. The price of aluminium relative to that of other building materials will however remain a primary factor governing its use. Any new process for the more economical extrac-

tion of aluminium from its ores or possibly aluminium bearing clays, resulting in a still further reduction in the price of aluminium would be of major importance in determining the extent of its future application.

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## Aluminium Castings

By S. A. J. Sage

*By the application of the results of research to the design of components and to the casting of both old and new alloys, a marked improvement in the quality of aluminium castings has been achieved. Furthermore, co-operation between designer and founder has resulted in the production of high-quality castings of considerable complexity. In discussing this question, the author refers to some aspects of moulding, casting, inspection and testing which have contributed to this result.*

WHEN a manufacturer constantly asks for a higher-quality product and is willing to help to obtain that product, it is inevitable that the finished article will be of a very high standard. When the manufacturer puts at the disposal of the producer the results of his own research and his service experience and the producer explains his technique and his limitations, there can be no doubt that both gain. It is the existence of this relationship in the aluminium-casting industry which has enabled the high-quality castings of to-day to be produced. With recent methods of casting and testing it can be assumed that, with high-class castings, the components will be to the specification desired, will be homogeneous throughout and with rare exceptions will not prove faulty during subsequent machining. The saving in man-hours and materials frequently more than justifies any expenses of preliminary testing after casting.

How has this been brought about? Mainly by the results of research being applied to the design of components and to the casting of both new and old alloys. There is now a much greater exchange of information between producer and manufacturer before a design is finally approved and put into production. In recent years both designers and producers have been helped by the more detailed research into new alloys, new methods of casting and better methods of testing. Gaps in the knowledge which originally existed have been filled and the results applied. The producers have been able to show advances in melting and avoidance of hydrogen pick-up. More is now known concerning the manner in which hydrogen—the main cause of pinholing in castings—enters the melt. Pick-up from the fuel or blast can now be avoided by advanced drying methods, whilst the use of electric furnaces, whether of the induction or resistance types, offers better control during melting. The greater use of rapid melting in large furnaces, followed by holding at slightly lower temperatures, in smaller furnaces, allows most of the included hydrogen to disperse. Better use of fluxes and



Casting an Armstrong Siddeley stator casting in RR.50. The casting weighs 61 lb. Note the asbestos sheets in the risers: these are used to delay solidification of the metal.

the introduction of chlorine-type cleansers further reduces the trouble.

#### Moulding Technique

The introduction of mechanisation into the foundries went hand in hand, with the greater demand for aluminium castings of good quality. The demand for more



Induction casing cover, sand-cast in RR.50. Weight 56 lb.

and better cores led to the introduction of sand-slingers, with their more even ramming, and new sands or modifications of old recipes. The introduction of a metal former and the use of sand-slinger and roll-over squeeze methods to one aero-engine cylinder-head casting necessitated a different casting technique. The head had then to be cast in a new mixture of sand, at a different angle and with redesigned gating and feeding arrangements. The new technique, however, gave more homogeneous castings, doubled output and allowed the original moulders to be released for more highly skilled jobs. Drying ovens have developed from the small hot cupboards situated in a corner of the foundry floor, operated by a labourer with his manual control of gas and air, to the immense vertical ovens with their more exact pyrometric control or the large horizontal ovens working with either high-frequency induction or infra-red heating methods, electronically controlled. The possibility that cores will have similar properties to those previously made is much greater in recent years, and this reproducibility has allowed high standards to be reached and maintained. The mechanical aeration and mixing control of sand has also paid dividends in getting better castings.

### Alloys

The alloys used have also undergone considerable change. The older alloys of the L.5 and L.11 types, which gave very good service years ago when demands on strength and intricacy were not very great, have been superseded in high-class castings by the more modern silicon alloys, the RR alloys and the newer Al-Mg alloys. The introduction of D.T.D. 424 and 428 for general engineering, with L.A.C. 10 for pistons, brought many problems, although it helped to bring into use much good-quality foundry scrap which would not otherwise have been used. Generous heads and gates overcame many of the problems and techniques were

developed which gave sound sand castings of moderate strength. The alloys at present in general use for high-strength castings are mainly L.35, D.T.D. 131B, D.T.D. 133C, D.T.D. 272, and D.T.D. 298, with L.33, L.35, D.T.D. 131B and LoEx. suitable for piston alloys. A summary of the mechanical properties of these various alloys shows the great advance in recent years, especially in strength and ductility.

| Alloy        | Sand Cast              |                 | Chill Cast             |                 |
|--------------|------------------------|-----------------|------------------------|-----------------|
|              | U.T.S.<br>Tons/sq. in. | Elongation<br>% | U.T.S.<br>Tons/sq. in. | Elongation<br>% |
| L 5 . . .    | 9                      | 2               | (11)                   | (3)             |
| L 11 . . .   | 7.5                    | 1.5             | (9)                    | (3)             |
| DTD 424 . .  | 9                      | 2               | 10                     | 2               |
| DTD 428 . .  | 8                      | —               | 10                     | —               |
| DTD 133C . . | 10                     | —               | 12.5                   | 3               |
| DTD 131B . . | 18                     | —               | 21                     | —               |
| DTD 272 . .  | 11                     | 2               | (13)                   | —               |
| DTD 298 . .  | 14                     | 7               | 17                     | 13              |
| L 33 . . .   | 10.5                   | 5               | 12                     | 7               |
| L 35 . . .   | 14                     | —               | (18)                   | —               |

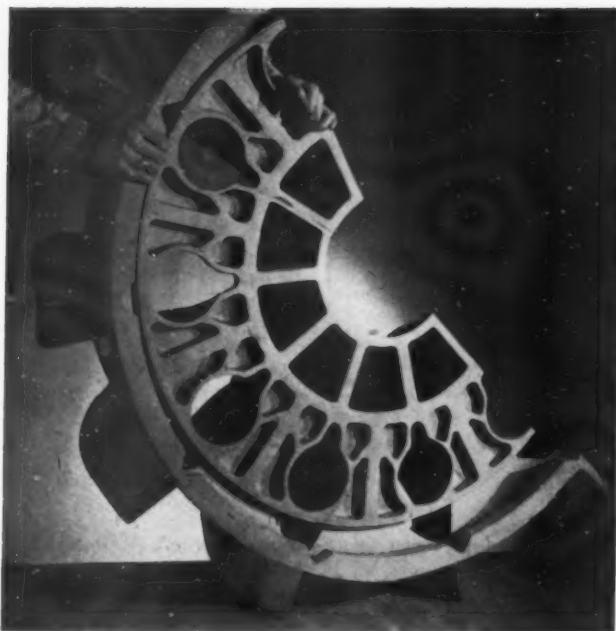
The aluminium-magnesium alloy containing 10% Mg exhibits very good properties as-cast, and efforts have been made to popularise it. Some success has been obtained in specific instances, but much has yet to be done to overcome many of the casting difficulties before it can be widely used. In connection with alloys and their properties, recent work at Birmingham University on hot-shortness

and the weld-cracking of the aluminium-silicon alloys has helped to explain some of the casting troubles met in the foundry with these and similar alloys. The progress of solidification of the various phases, throughout a section, and the attendant stressing need careful control in the complex alloys to avoid cracking and pin-holing. Some years ago a problem was encountered in a new alloy in which the lowest melting-point phase was thought to contract rapidly on solidification, resulting in intercrystalline cracking. Recent work on the solidification of aluminium alloys has shown the need for balancing the alloy so that the low-melting-point phases completely fill any microscopic voids between solidified high melting-point phases. The work of Hume-Rothery, Raynor, and their colleagues on phase diagrams of the complex alloys at first sight seems wholly academic, but in reality it has far-reaching repercussions in the foundry. The greater the knowledge available, the better can a problem be explained and overcome.

### Casting Methods

A method of casting under reduced pressure has been evolved, and whilst it is as yet limited to specialist firms who have built up their own techniques, castings can now be produced which have very thin and intricate sections without the usual troubles of mis-runs and oxide films. The use of pressure has not been applied commercially to sand castings, but great strides have been made in the die-cast sections of the aluminium-casting industry. An attempt was made several years ago to produce several intricate aluminium-alloy castings for jet aero engines by the "lost-wax" process, but as far as is known this method did not extend to quantity production. Similarly, the method of using plaster moulds to give cooling intermediate between sand and chill castings has been used on specific components with fair success in the U.S.A., but does not seem to have had any similar results in this country.





An air intake throat, sand-cast in RR.50. Weight 160 lb.

One distinct advance in the improvement of castings can be attributed to the practice of ingotting fettled metal prior to remelting. Many years ago it was common practice even in foundries of good repute to mix part virgin metal and part sprues in the melt. It was found, after much detailed work had been carried out, that excessive gas and oxide were frequently introduced into the new melt by this method. As a result of this experience it has been found advantageous to remelt all fettled scrap in a separate furnace and thoroughly cleanse and de-gas it by means of fluxes and temperature control prior to casting into ingots. Analysis follows and the ingots are either remelted to bring them back to specification or added to virgin melts in suitable proportions according to the specification being fulfilled.

### Inspection

Much of the credit for the improvement in the quality of castings can be attributed to the rigorous inspection and testing methods now employed as common practice by those firms demanding the highest quality product. When a casting has been made and fettled, assuming it is a prototype model, it is first examined visually for obvious defects and then, if satisfactory, for dimensions. The wider use of proving gauges working off a suitable datum line has saved countless hours of subsequent machining time by showing immediately whether or not the finished dimensions can be obtained from a casting. It was always disappointing and wasteful to find, when machining intricate castings, that a casting would not pass final inspection due to walls and cores not being correctly placed. It has become the usual practice, in recent years, with high-class castings, for the producer to use a proving gauge and scribe on the casting the datum line that the foundry inspector made to prove that the casting was dimensionally correct.

X-ray examination is now the rule for first-class castings and much has been learned by this means of inspection. Any internal faults are shown up and from this examination the casting technique is either approved or modified. With intricate castings this method has proved invaluable in showing how, by introducing new gating methods or chill positions, castings can be produced with a minimum of metallurgical defects. To be able to show that a casting is either porous or sound without destroying it has been one of the great advances in the industry and one of the pillars on which good quality products have been built. Along with X-ray testing, have been developed the various crack-detecting methods. The old-established oil and chalk method is still widely used for this purpose, although the fluorescent method, developed during the last few years, has found favour in some quarters. It is really only a variation of the older method; a fluorescent penetrant is used and, after the surplus has been removed from the surface, the casting is examined in ultra-violet light when any cracks are seen as bright lines on the dark background of the casting. This method of testing has also been found helpful in the solution of machining troubles. During machining much ingenuity is necessary in the holding of the casting. If the number of components is large, metal-holding jigs for machining are the

rule, but in the case of experimental castings, where the number involved is usually small, free-hand methods of holding are often used. Crack detection after machining has sometimes shown where cracks have been caused as a result of oversteering thin sections by clamping on to machines. This is connected with the design of the casting which should incorporate the necessary machining locations. Other forms of cracking are found by these tests, one type of which is due to the release of internal stresses when the surface of the casting is removed by machining. This condition is usually overcome by heat-treatment, but it sometimes occurs on experimental prototypes.

### Rig Testing

After the experimental casting has been satisfactorily machined, the manufacturer applies his special tests, and it is from the results of these that the casting is approved, or modified to meet the new conditions. Full-scale testing gives valuable data, although, if the casting does not fail, there is often some doubt as to whether it has been made too robust and could be reduced in weight to advantage. In order to test the casting without destroying it, full-scale static tests can be carried out by using electrical-strain gauges or by using one of the various methods whereby a brittle lacquer is sprayed on to the casting. As the brittle coatings and strain gauges have been calibrated against standard loads, when the casting is stressed by calculated loading the resulting pictures indicate the stresses set up at different positions on the casting. If the casting shows that oversteering is occurring at strategic points this method saves time and money, and the designer can work on the new data for redesigning a modified casting. If, however, stress-strain data give satisfactory results, the casting can be given a test equivalent to a full-scale running test with applied fatigue loads on equipment such as the Schenk fatigue-testing machine. This machine allows



both static and dynamic stresses to be applied either to a complete casting or to specific sections of that casting and valuable information can be obtained in this way. The effects of sharp radii, blind stud holes, various stud and bolt shapes, and of bosses and bolt flanges, etc., can be studied, whilst the effects of welding, heat-treatment and such special processes as shot or roller peening can be examined before the casting is built into its final assembly. As much ingenuity must be applied to the designing of the jig which holds the casting in the testing machine as to the casting itself, because the jig is given a fatigue test at the same time. It is extremely disappointing when doing a series of tests at increasing loads to have the jig fail instead of the section or casting under test. This, of course, is overcome by having the jig of such robust proportions that it is lightly loaded in comparison with the casting.

### Creep

The development of jet engines has meant that aluminium-casting materials which were formerly used satisfactorily at normal temperatures are now required to run at higher temperatures. Data have been compiled from Wohler fatigue tests, but these have to be considered along with creep data before the results can be applied to the design of components required to run at elevated temperatures. This invariably means that sections have to be thickened and sometimes stiffened, but instances have occurred where flexibility has been found to give satisfactory results under specific, arduous conditions. The use of narrow ribs to strengthen diaphragm types of castings has been modified in recent years. Highly-stressed castings are now being produced in which the ribs have either been deleted and the casting thickened on the diaphragm or the ribs have been considerably widened, with less depth, to give satisfactory running results. This redistribution of stress has frequently helped the producer as less cracking and drawing is found at the base of the new ribs than was found formerly at the base of the narrow ribs with their sharp change in section.

Failure of a casting on test usually involves metallurgical examination. This examination has been noticeably improved in recent years with better microscopes, better furnace and pyrometer control, the great use of X-ray diffraction apparatus and, more recently, the wider use of the electron microscope. The X-ray diffraction and electron microscope apparatus have helped greatly to explain the internal and surface phenomena which occur when alloys are heat-treated and stressed.

All the above processes are involved in the evolution of aluminium-alloy castings, and it is difficult to state which has been most effective in improving their quality. Both the casting and testing techniques have improved with changing conditions and wider knowledge. The universities, the manufacturers, the founders, the testing equipment manufacturers and the scientific societies have all combined to give each other the benefit of their experience and the urge within the industry to demand the best, and not be satisfied with the second best, have all contributed to the improvement of aluminium-alloy castings.

*The Author acknowledges the courtesy of High Duty Alloys Ltd. and Messrs. Armstrong Siddeley Motors Ltd. for permission to reproduce the photographs.*



An Avery-Schenk fatigue testing machine claimed to be the only machine capable of applying varying pulsating stresses of a high order. This machine has proved invaluable for development work on airscrew blade materials.

### Defence Services Research Facilities Committee

At the invitation of the Council of the Royal Society, the Lords Commissioners of the Admiralty, the Army Council, the Air Council and the Ministry of Supply have appointed representatives on a Defence Services Research Facilities Committee. The terms of reference of the new Committee are as follows:—

“To consider proposals for the use of Service facilities and personnel for assisting scientific research, and to make recommendations to the Council of the Royal Society, the Lords Commissioners of the Admiralty, the Army Council and the Air Council.”

The Committee has been constituted as follows:—

*Chairman:* Sir Geoffrey Taylor, F.R.S.

*Royal Society:* Professor P. M. S. Blackett, F.R.S.;

Sir Harold Spencer Jones, F.R.S.; Dr. A. C. Menzies; Mr. F. S. Russell, F.R.S.

*Admiralty:* Vice-Admiral A. G. N. Wyatt (Hydrographer); Mr. F. Brundrett (C.R.N.S.S.).

*War Office:* Lieut.-General Sir Kenneth Crawford (D.C.I.G.S.); Dr. O. H. Wansbrough-Jones (Scientific Adviser to the Army Council).

*Air Ministry:* Air Vice-Marshal C. E. H. Guest (Assistant Chief of Air Staff-Operations); Mr. G. S. Whittuck (Head of S.6).

*Ministry of Supply:* Dr. F. J. Wilkins (Principal Director of Scientific Research—Defence); Mr. H. M. Garner (Principal Director of Scientific Research—Air).

The Committee proposes to conduct its business through panels of scientists and Service representatives who are specially interested in specific projects and at its first meeting panels were formed to cover the following subjects:—(a) Submarine Gravity Measurements; (b) Surplus Explosives; (c) Magnetic Survey; (d) Aerial Photography; (e) Scientific Expeditions.

Scientists wishing to submit proposals for consideration by the Committee should communicate their suggestions in the first instance to the Assistant Secretary, the Royal Society, Burlington House, London, W.1.

# Developments in the Metallurgy and Technique of Welding Aluminium Alloys

By P. T. Houldcroft, B.Sc.Eng. (Met.)

*The increased use of aluminium and its alloys in recent years is due in no small measure to the greater use of welding in their fabrication. This is true of practically all the aluminium-consuming industries, but especially of those using sheet and sections. This contribution to progress has resulted from developments in the metallurgy and technique of welding aluminium alloys, some of the main aspects of which, as well as some of the difficulties, are discussed in this survey.*

**A**LUMINIUM itself and many of the medium-strength alloys can be welded readily by several methods. The high-strength materials, including alloys of the duralumin type present certain difficulties as regards fusion-welding, but may be joined satisfactorily by resistance-welding methods. Spot-welding of these alloys is now well established, and flash-welding techniques are in an advanced state of development.

## High-Strength Materials

The excellent resistance of aluminium to corrosion and many forms of chemical attack and the ease of welding, make it very suitable material for the fabrication of vessels for the chemical and allied industries. Strength considerations, however, limit the use of aluminium and the lower alloys in the structural field, and research has naturally been directed towards the development of methods for welding the high-strength materials.

The high strength of many of these alloys is developed by heat-treatment, and the properties of some of the medium-strength alloys are improved by work-hardening. When a welded joint is made in these alloys, the material near the weld is heated and reduced in strength as a result of over-ageing or of annealing. In this respect arc-welding methods are preferable as the applied heat, although more intense, is localised. The heat-affected zone of an arc weld may be only a few per cent. of the width of that in a similar weld made by gas.

Another disadvantage in welding these strong alloys is their relatively poor strength in the cast condition. The casting properties of an alloy influence greatly the strength of the welded joint, although direct comparisons of the strength of welds and ordinary castings cannot be made because of the highly-specialised conditions of solidification pertaining in a weld.

In work on the gas welding of high-strength aluminium-zinc-magnesium-copper alloys, Pendleton<sup>1</sup> obtained strength efficiencies of about 65% from as-welded joints. These welds were made in 18, 14, and 10 S.W.G. sheet with filler wire of the same composition as the parent material. Difficulties were experienced due to cracking of the weld, especially when welding was made under restraint. There was also internal porosity in the heat-affected zone. By heat-treating the joints after welding, efficiencies of over 90% were recorded.

Working on other high-strength alloys, Harmer and Brooks<sup>2</sup> obtained joint efficiencies of between 44 and 71% in the as-welded condition, when core and filler wires of the same material as the parent plate were used. Higher and more consistent strengths were obtained from arc welds than from gas welds.

The fundamental metallurgy of welds in high-strength alloys has been discussed by Apblett<sup>3</sup> who also tested

welds in  $\frac{3}{8}$ -in. thick plate of a duralumin-type alloy, arc-welded with an aluminium-5% silicon electrode. Tensile strengths between 12 and 13 tons/sq. in. were obtained. Apblett points out that this type of electrode does not permit full use to be made of the high strength of the parent material because of the low strength of the deposit. There is evidence<sup>2</sup> that higher strengths may be obtained by welding the high-strength alloys with electrodes having core-wire of a similar composition to the parent material. An added advantage is the possibility of improving the strength of the joint by heat-treatment. In practice, however, the choice of electrode may be determined by such considerations as the tendency for cracking to occur in the weld.

A technique for welding aluminium alloys without the formation of fused or heat-affected zones has been developed by the General Electric Co. The joining is effected at room temperature solely, by the application of pressure to the parts to be joined. Soft aluminium alloys are joined most easily in this way. However, the advantages of joining without heat will doubtless stimulate the development of an improved technique for joining the heat-treated alloys.

## Medium-Strength Alloys

Due to their good strength and resistance to corrosion the Al-Mg-Si alloys and the binary Al-Mg alloys are particularly suited to structural work.

An investigation of the mechanical properties of arc-welded joints in structural components of an Al-Mg-Si type alloy<sup>4</sup> indicates that joint efficiencies of a maximum of about 50% may be obtained. The highest tensile strengths were observed in butt-welded components in which the reinforcing bead had not been removed. Fatigue-strength efficiencies were at a maximum in butt-welded joints where the reinforcing bead had been machined away. The joints were made using an aluminium-5% silicon electrode and were examined without previous heat-treatment. Tests on a structural type specimen have also been carried out by R. L. Moore,<sup>5</sup> who, on the basis of tests on fillet-welded butt-strap panels suggests an ultimate shear stress for design purposes of 7-8 tons/sq. in.

A considerable improvement in weld efficiency as a result of heat-treating the welded joint has been noted by several workers.<sup>5, 6</sup>

The occurrence of cracking in gas welds in the Al-Mg-Si type of alloy has been observed<sup>7</sup> and it was suggested that this was influenced by the presence of copper in the parent material. No trouble from cracking was experienced with arc welds.

The Al-Mg alloys containing 5 and 7% of magnesium possess attractive mechanical properties in both the wrought and cast conditions. Unlike the Al-Mg-Si

alloys they are not susceptible to heat-treatment and are normally supplied in the work-hardened condition.

In gas-welding the Al-Mg alloys containing higher percentages of magnesium difficulties may often be encountered, due to porosity, in the heat-affected zone (Fig. 1). The porosity causes a loss of strength and a swelling adjacent to the weld<sup>8</sup>. This tendency to develop porosity arises from the ease with which the alloys react with water vapour at high temperatures. The mechanism by which the porosity develops involves the diffusion of atomic hydrogen, generated at the

small quantity of magnesium caused the appearance of a heat-affected zone and reduced the ductility of the welded joint. Due to unsoundness in the weld deposit and slower rates of cooling the efficiency of joints in sheet thicker than 14 S.W.G. was reduced. No results for arc-welds in this alloy are available, but with the higher rates of cooling associated with this method it seems possible that the high weld efficiency could be maintained.

The Al-Si-Cu alloys are easily worked and have possibilities for medium-strength structural work involving fabrication by welding.

### Porosity

Weld-metal porosity of the pin-hole type is frequently observed in arc-welded aluminium alloy joints. Opinions vary as to the magnitude of the effect of such porosity on the strength of the joint but the advantages of its elimination are evident.

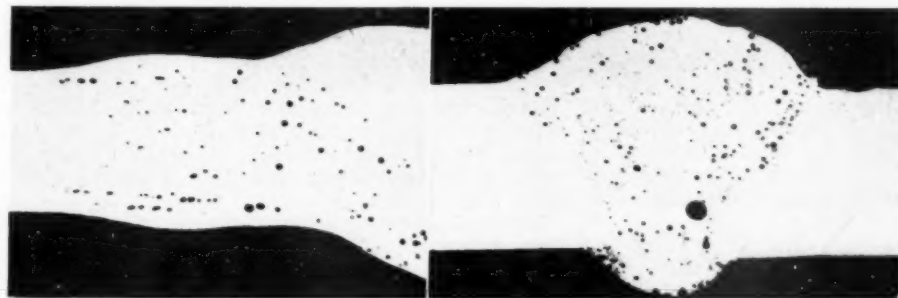


Fig. 1

Fig. 2

Fig. 1.—Porosity in the heat-affected zone of a gas weld in 10 S.W.G. aluminium—7% magnesium alloy sheet. Fig. 2.—Porosity is absent in the heat-affected zone of this arc weld in  $\frac{1}{2}$  in. thick aluminium—5% magnesium alloy plate. This material was susceptible to porosity when gas welded.

surface of the metal by the reaction of water vapour with magnesium ions,<sup>9</sup> to discontinuities in the body of the metal where it may re-associate to form molecular hydrogen. Much of the trouble from porosity in welding may be traced back to the casting stage of the parent material.<sup>10</sup> It has been shown, however, on a laboratory scale, that by a suitable melting and degassing technique, material can be produced which does not develop porosity when welded.<sup>11</sup> Part of this special foundry technique consists in excluding from the melt certain alkali and alkaline earth elements which promote the reaction with water vapour. By these and other means material of low gas content and low "reactivity" can be produced.

Using this specially-prepared material, welds of high efficiencies have been made, strengths exceeding 20 tons/sq. in. having been obtained for gas welds in aluminium—7% magnesium-alloy sheet.

Porosity is not normally observed in the heat-affected zone of an arc weld in thick plate (Fig. 2). This may be due to the more rapid heating and cooling associated with arc-welding. However, other problems are encountered in arc-welding, among them being weld-metal porosity and excessive loss of magnesium from the core wire, due to the high temperature of the arc.

### New Medium-Strength Alloys

With the object of developing a medium-strength alloy with satisfactory welding characteristics, work has been done by the British Non-Ferrous Metals Research Association on the Al-Si-Cu series of alloys.<sup>11,12</sup>

Gas welds in an alloy-containing silicon 5% and copper 2½% were found to have high weld efficiencies, and hardness surveys across the weld showed that there was practically no heat-affected zone. This latter effect was probably due to the slow response of the alloy to precipitation ageing treatments. The addition of a

Porosity originates from water vapour which has dissociated during welding with subsequent absorption of the atomic hydrogen by the molten metal. Moisture may be associated with the oxide skin naturally occurring on the parent material. For this reason, cleaning of the edges to be joined, and the use of preheating is usually recommended. Moisture is frequently contained in the coating of the electrode, and this is the chief source of porosity in arc-welds. Electrode coatings are mainly halides of the alkali metals and are of a very hygroscopic nature; moreover, the removal of the last traces of water from such salts is extremely difficult. The drying of electrodes before use is a universally accepted practice, but it is doubtful whether at the low-temperatures usually employed the treatment is sufficient. It has been claimed<sup>13</sup> that freedom from porosity in welds can be obtained by baking the electrodes at approximately 500° C., but the efficiency of this treatment may depend, to some extent, on the composition of the core wire. Electrode coatings heated to this temperature are very fragile.

Electrodes are often coated by a dipping process involving the use of an aqueous slurry. By dipping the wires, instead, into a mixture of fused salts electrodes have been produced which were capable of making very sound welds.<sup>14</sup> There are, however, practical difficulties involved in the use of such electrodes.

A satisfactory solution to the problem of porosity in arc-welds would advance greatly the applications of this process.

### Cracking

The problem of cracking in aluminium alloys is the subject of a series of investigations being carried out by the Aluminium Development Association Welding Research Team at the University of Birmingham.



Cracking at temperatures above the solidus is held to be the cause of most industrial failures in welding the aluminium alloys<sup>15</sup> and early work by the team was concerned with the relation of cracking to hot-shortness. It was confirmed by high-temperature tensile tests that a hot-short range exists in the aluminium-silicon system of alloys, the extent of which is dependent on the composition of the alloy. More detailed work along the same lines has been published recently<sup>16</sup> in which high-temperature tests were carried out under conditions more nearly approaching those experienced in casting and welding. These tests which were performed during cooling from the liquid state and after rapid heating of chill-cast alloys have shown that the most extended brittle range occurs with a lower silicon content than under equilibrium conditions.

Cracking above the solidus has been discussed critically by Pumphrey and Jennings<sup>17</sup> who have also considered the problem mathematically. Cracking below the solidus depends on the ductility of the metal, conditions of restraint, and the amount of cracking which occurs above the solidus.<sup>18</sup>

Work involving a special type of ring casting, and welding tests has permitted a number of alloys to be classified according to their susceptibility to cracking in casting or welding. The degree of cracking observed in restrained weld tests on alloys of aluminium with silicon, copper and magnesium shows quite good correlation with the results of the cast-ring cracking test. These results confirm a previous theory that the tendency for cracking to occur in a binary alloy is greatest at the composition having the longest range of solidification. An explanation has been offered for the deviation of the alloys of aluminium with manganese and with zinc from this simple theory.<sup>15, 19, 20</sup>

An investigation has been carried out by Mader<sup>21</sup> using a cross-type of weld test. Of the materials subjected to this test the binary Al-Mg alloys showed the least tendency to crack. Cracking was most severe with the Al-Mg-Si and Al-Mg-Mn type alloys.

#### Welding Generators

The need for fabricating large aluminium structures by welding has focused attention on arc-welding methods since these alone are capable of welding thick plates economically.

Metal arc welding of aluminium is carried out using a D.C. welding generator with the electrode positive. The characteristics of welding generators are discussed in a paper on the welding of aluminium alloys by A. Schärer.<sup>22</sup>

It is suggested that some D.C. generators, while suitable for the welding of steel, can cause bad starting, extinction of the arc during welding and an irregular deposit when used for welding aluminium. A cross-field type generator, which enables the voltage to recover rapidly after a short circuit, is recommended.

#### Argonarc Welding

The inert gas-shielded arc-welding process has had considerable success in the field of welding magnesium alloys and stainless steel and is now being employed for welding aluminium. In this process the arc is struck between a permanent tungsten electrode and the work. An inert gas, formerly helium but now almost universally argon, is used to shield the weld-pool, filler wire and surrounding metal from oxidation during welding. To stabilise the arc and permit easy striking, a high-frequency voltage is superimposed on the alternating

welding current, which is normally used for the welding of aluminium by this process. Early work in Britain on the application of the process to welding magnesium-rich alloys is recorded in the Symposium on the Welding of Light Alloys.<sup>23</sup>

When welding aluminium the tough adherent oxide film of alumina must first be removed. In gas and metallic arc welding this is effected by chemical means (fluxing), but in the argonarc process, the oxide is dispersed electrically.

The advantages of fluxless welding are apparent and with the high speeds of welding which can be obtained and suitability for mechanisation, a wide use of the argonarc process is assured, especially if the price of argon can be reduced. A review of recent progress in argonarc welding has been made by R. R. Sillifant.<sup>24</sup>

With the need for welding thick plates, lightweight torches with water-cooled heads have been developed capable of handling currents up to about 400 amps. In some welding plants high open circuit voltages are being used to overcome rectification effects. In these plants the high-frequency stabilising voltages need only be used for striking the arc.

A D.C. component is present in the normal argonarc welding circuit when this process is used for welding aluminium. The removal of this component, which causes an unbalanced A.C. wave-form, results in a better shaped cleaner weld and improved penetration. By including condensers, or a 6-volt biasing accumulator in the circuit, the D.C. component may be suppressed.<sup>25</sup>

In a novel development of the argonarc process<sup>26</sup> the tungsten electrode is replaced by a thin filler wire which is fed into the weld pool at high speed. The torch in this method takes the form of a pistol with automatic controls incorporated.

#### Resistance Welding

The low electrical resistance and high thermal conductivity of aluminium alloys necessitate the use of high heat inputs and these are conveniently supplied by a stored energy type machine.

In spot-welding, factors such as electrode pressure and current and their changes, with time during the welding cycle are of great importance.<sup>27, 28</sup> The need for obtaining consistent results and hence for controlling these factors, has made instrumentation and the use of such devices as electronic timers imperative. With carefully controlled conditions it is possible to spot-weld up to four thicknesses of 19 S.W.G. clad duralumin sheet.<sup>29</sup> Methods for measuring current, voltage and electrode-load cycles have been discussed by Bennett and Dixon.<sup>30</sup> The simultaneous reading of these variables provides a valuable tool for research purposes.

Surface preparation is also critical and considerable work has been done in developing suitable methods.<sup>31, 32, 33</sup> Chemical methods of surface preparation are usually preferred.

It is claimed<sup>34</sup> that low-capacity machines of the type used for steel can be used for the welding of aluminium and its alloys when the material is preheated. This is effected by sandwiching the aluminium between steel strips, thereby increasing the resistance of the circuit and the heat input. The steel strips can, it is said, be removed without damage or sticking to the aluminium.

In common with spot-welding, flash and butt-welding of aluminium alloys calls for careful control of welding conditions. R. Della-Vedova and E. A. Reynolds<sup>35</sup>



found that the most critical variable was the timing of the current cut-off. These workers found that between certain limits, which they defined, a duralumin-type alloy could be flash-welded on equipment normally used for steel. A study of the temperature distribution in flash-welding, using thermocouples placed in the stock, has been reported recently.<sup>36</sup> One result of this investigation is the conclusion that the secondary voltage has no influence on the temperature distribution if flashing is continuous. Information on resistance welding, including a useful review on flash- and butt-welding will also be found in the literature.<sup>37, 38, 39</sup>

### Pressure Welding

Although specialised in its application, the process of pressure welding the light alloys without fusion has many commercial possibilities. The surfaces of the parts to be joined are prepared and then pressed together in heated dies. During welding there is a certain amount of plastic flow which breaks up the oxide film on the surface and ensures good metal contact. This method of joining has been extensively investigated by R. F. Tylecote.<sup>40</sup> The relation between the temperature and pressure required for producing joints in a number of commercial materials has been determined. Recent work by the same author<sup>41</sup> deals with the pressure welding of the more readily weldable materials down to room temperature, with attempts to improve the strength of welds in the more readily weldable alloys, and with the effect of oxidation before welding, and corrosion tests. The considerable potential applications of the process, including the adaptation of a conventional projection weld are also described. Mention is made also of the seam welding of pure aluminium at room temperature with a deformation of not less than 60%.

Considerable attention has been given to the cold-pressure welding of aluminium alloys and other metals by the General Electric Co.,<sup>42</sup> who found that the method of surface preparation is critical. Filing or the use of abrasive is not permissible as there is a tendency for material to be re-embedded in the surface. Chemical methods, although satisfactory for spot-welding, cannot be used for the cold-welding process because the presence of a fluid film after cleaning has been found to upset welding conditions. The G.E.C. have adopted scratch brushing as a means of preparation. A power-driven brush is recommended, and the material must be held against this until the wires drag at the surface. A number of materials have been classified according to their suitability for joining by this process, on the basis of the minimum reduction in thickness necessary to make a weld. Super-purity aluminium is most easily joined, zinc and silver present the greatest difficulty. The commercial applications of the process are many and varied, including, the seam welding of tube, the joining of strip and wire and the joining of aluminium sheet to copper.

### Testing of Welds

Because of the heterogeneous nature of a welded test-piece the results of mechanical tests must be interpreted with care. There is general agreement about the difficulties associated with tensile testing, but much diversity of opinion exists as to the merits of the bend test. A report which is intended to clarify the position has been published by the B.W.R.A. Committee on the testing of welds in light alloys.<sup>43</sup>

Of the non-destructive tests used for examining welds radiography is the most important. A particular use is

made of the method in the testing of spot-welds, where most of the spot-welding defects are revealed regardless of the composition of the sheet material.<sup>44</sup>

It is possible to correlate the radiographic examination of spot-welds with both static and fatigue strengths of the welded joints.<sup>45, 46</sup> The method of correlation involves a measurement of the nugget size and "dark ring" diameter. This is more accurate in materials of certain compositions and sheets which are clad with metal having radiographic absorptive properties different from the core material.<sup>44</sup>

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# Some Factors influencing the Corrosion Resistance of Aluminium

By E. G. West, Ph.D., F.I.M.



Eros Statue in Piccadilly

**E**ROS has again been in the news and yet again have the journalists described Gilbert's masterpiece as a bronze statue, forgetting that it has become a symbol of the ability of aluminium to withstand London's corrosive atmosphere unimpaired. It is strange to reflect that the belief of Sir Alfred Gilbert, backed by a similar faith on the part of his supporters, in the suitability of the then new metal to stand the test of time in such conditions would not have been shared by many "experts" had the statue been cast in aluminium fifty years later.

The fact is that to-day so much research has been pursued into the corrosion characteristics of the aluminium-base materials that there is a very real danger of engineers and designers being afraid — quite wrongly — to specify aluminium at all unless it is heavily protected against all forms of attack. That this attitude is unjustified is shown by a moment's reflection on the many long-standing uses of bare aluminium. At least a third of all the aluminium and aluminium-rich alloy produced to date has been put into service without the application of any surface coating — cooking utensils and large-scale food-processing equipment; chemical plant, electrical conductors and steel-cored cables; internal combustion engine components including radiators; foil insulation; roofing sheets and rainwater goods; scaffold tubes and many other building items; sinks and draining boards; ventilating equipment, excavator buckets, truck floors — the list could be extended.

Aluminium does not, of course, corrode in the same way that steel rusts and there is much to be said for the views recently put forward by Woollard<sup>1</sup> who made the

*Despite the successful use of aluminium under conditions that impose considerable restrictions on the use of other base metals, misconceptions continue to exist regarding the corrosion resisting characteristics of this material. For many applications no protective surface finish is needed, but it is necessary to choose the most suitable alloy for a particular application. In this article are given some recent trends towards a better understanding of the corrosion resistance of aluminium and some of the new means of protection are discussed.*

interesting suggestion that the white to grey film on aluminium should be called "greyst". There are genuine misconceptions which are often held as a result of insufficient knowledge but it must also be admitted that there have been unfortunate mistakes in the past and it is necessary to choose the most appropriate alloy for each specific application and, where necessary, to apply a suitable surface finish.

The present article touches upon some of the more recent trends in our understanding of the corrosion resistance of aluminium, illustrated by reference to applications, and discusses some of the newer means of protection.

## The Role of the Oxide Film

Aluminium is, of course, one of the most reactive metals but the existence of a protective oxide film was realised very early in the metal's commercial career. For example, in 1890 Richards<sup>2</sup> noted that "... objects of commercial aluminium had, after a long exposure, become coated with a very thin film which gives the surface a dead appearance ... The oxidation, however, does not continue for the film seems to be absolutely continuous and to protect the metal underneath from further oxidation." This observation has been confirmed and the many quantitative data now available allow accurate assessment of its value in practice to be made. Very largely the resistance of aluminium and the aluminium-base materials to corrosive attack depends on the chemical and other properties of the oxide film, and on the rate of film formation in the air or in the many media to which the metal may be exposed.

One of the best-known attempts to measure the rate of film formation on aluminium was that of Vernon<sup>3</sup> who exposed freshly scratched-brushed samples to the atmosphere at ordinary temperature, and although this work was subject to certain errors his results provided a useful basis for other investigations. More accurate work reported by Keller and Edwards<sup>4</sup> on films at

<sup>2</sup> Richards, "Aluminium" 2nd Edition; Henry Carey Baird and Co., Philadelphia (1890).

<sup>3</sup> Vernon, *Trans. of the Faraday Soc.*, **23**, pp. 150-155, (1927).

<sup>4</sup> Keller and Edwards, *Pittsburgh International Conference on Surface Reaction*, 1948, pp. 202-211.

<sup>1</sup> E. G. Woollard, "Durability of Aluminium," *Times Review of Industry*, May, 1948, p. 21.

normal temperatures and by Steinheil<sup>5</sup> and Gulbranson<sup>6</sup> on films at raised temperatures, shows that Vernon's results were basically sound. The oxidation rate curves are made up of two parts, namely, a logarithmic curve for the first two hours at normal temperatures and thereafter following the exponential law to give films of the order of 100 Å. As, however, the metal always carries a thin film it is likely that the initial period can be neglected and an exponential curve may be assumed to hold for all practical purposes. Thickening of the film by heating is appreciable and the character of the film so formed is unfavourable to attack but this is not a practicable means of increasing corrosion resistance in the case of aluminium. The anodic oxidation processes, however, allow films to be increased from the normal thickness to thicknesses of several thousandths of an inch.

The oxide formed in the normal manner on aluminium is considered to be amorphous but X-ray and electron diffraction investigations have revealed that one or more of the hydrated and crystalline forms of alumina may be present on the surface, depending on the method of production of the film. The amorphous oxide formed at normal temperatures in air is usually hydrated to some extent, but sometimes the amorphous variety is changed

<sup>5</sup> Steinheil, *Ann. d. Phys.*, **19**, p. 465 (1934).

<sup>6</sup> Gulbranson, *Review of Scientific Instruments*, **15**, pp. 201-204, (1944).  
*J. Phys. and Colloid Chemistry*, **51**, pp. 1087/1103, (1947).



Fig. 2.—East Liberty Presbyterian Church, Pittsburgh, Pennsylvania. An aluminium batten seam-roof was used over the Naves, the Chancel, the East and West Transsepts, and on the set-backs of the Tower. Other aluminium applications include windows, snow guards on the slate roof areas, exterior and interior stair railings, gutters and conductors, and rods and cables for lightning protection.

The architects wanted a dull grey tone on the exterior aluminium work, and to-day the metal has a pleasing grey patina. The church management, after eleven years, reports complete satisfaction with the aluminium applications.



By Courtesy of A. P. V., Ltd.

Fig. 1.—Close-up view of a weld in an aluminium fermentation vessel after 38 years service at Messrs. Fuller, Smith and Turner's Brewery (reduced to half-size linear).

to one of the crystalline forms, probably again with some hydration. For example, anodic films are often sealed by immersing them in hot water and after such treatment the oxide is probably the alpha alumina mono-hydrate. When amorphous alumina is heated to temperatures above about 500°C. it is transformed to one of crystalline forms, first to  $\alpha$  alumina and then at temperatures above 1,000°C. the  $\gamma$  form is obtained. Gamma alumina corresponds to corundum but this is not, of course, normally formed on the solid metal. Oxide films resulting from exposure to the weather are probably chiefly beta alumina tri-hydrate. These crystalline forms are probably impervious to oxygen and the observations of Pilling and Bedworth<sup>7</sup> indicate that oxidation at 600°C. ceases when the film is 0.00002 cm. thick. The exact modes of film formation at low as well as high temperatures are not fully agreed but the views of Evans,<sup>8</sup> Mott<sup>9</sup> and others<sup>10</sup> are worthy of close study not only in connection with corrosion and protection but also insofar as other phenomena are concerned, e.g., gas reactions, frictional properties and pressure welding.

The oxide layer present on aluminium alloys differs in several important particulars from that on the pure metal. It is, in general, less continuous and particles of foreign elements at the surface constitute weak spots in the protective film. Elements in solid solution, however, have a less harmful effect but may result in the development of a mixed oxide layer. Thus, de Brouckère<sup>11</sup> showed that on the aluminium-magnesium alloys there was a considerable amount of magnesium oxide present, the quantity and position of the magnesia depending on the temperature of oxidation. The presence of appreciable proportions of magnesia in the film on these alloys is clearly an important factor in their successful use in contact with sea water and other chloride-containing media.

<sup>7</sup> Pilling and Bedworth, *J. Inst. of Metals*, **59**, p. 573 (1923).

<sup>8</sup> Evans, *Trans. Amer. Electrochem. Soc.*, 1943, **83**, 335.

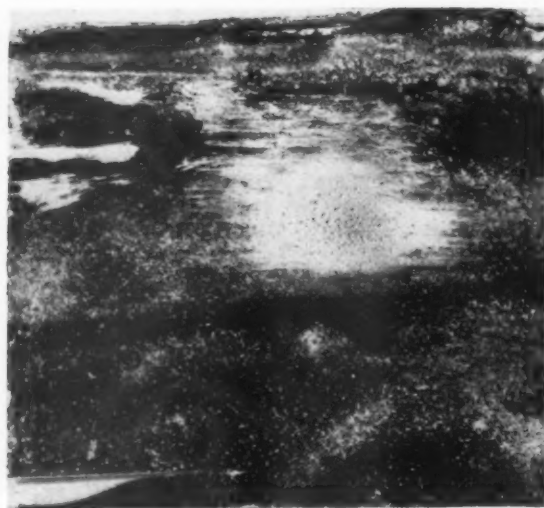
<sup>9</sup> Mott, *Trans. Faraday Soc.*, 1939, **35**, 1175; *Mettall. Abstr.*, 1939, **6**, 523.

<sup>10</sup> E.g. Lustman, *Trans. Amer. Electrochem. Soc.*, 1942, **81**, 372. Cabrera, *Comptes Rendus*, **224**, 1558-1560 (1947).

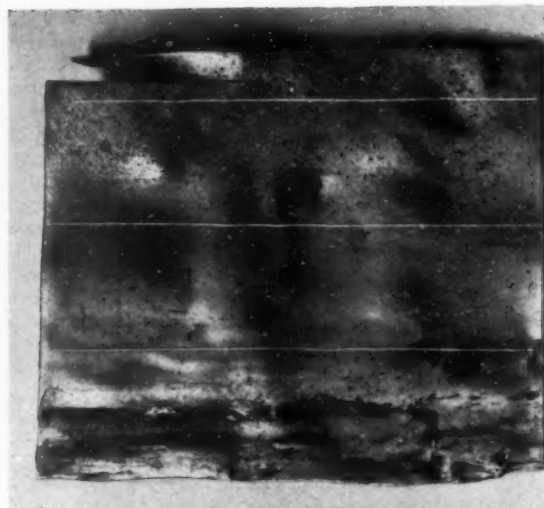
<sup>11</sup> Brouckere, *J. Inst. Met.*, 1945, **71** (3), pp. 131-147.

<sup>12</sup> Britton, "Hydrogen Ions," p. 209. Lond.: Chapman and Hall, 1929.





(a) Upper surface.



(b) Under surface.

Fig. 3.—Showing the surface of aluminium roof samples taken from the roof of a Dusseldorf bank after 34 years satisfactory service (reduced to half-size linear).

The protection afforded by the oxide film is, therefore, dependent largely on continuity and chemical inertness but account must also be taken of structure and electrical characteristics. Consideration must also be given to the effect of any corrosion product present in addition to, or in place of, the oxide.

Alumina is well known to be inert towards many reagents and it is amphoteric, i.e., it may react as an acid or a base. The salts formed readily hydrolyse in solution and the hydrated oxide is relatively insoluble within the pH range 4–11, approximately.

The oxide film is susceptible to penetration by many ions and a general order of penetrating ability has been given<sup>13</sup> as follows: chloride, bromide, iodide, fluoride, sulphate, nitrate, phosphate — in descending order.

The electrical resistance of the oxide film is high thus reducing the current which may flow in electrochemical corrosion and hence reducing the severity of attack. Impurities present at the surface or the absorption of ions by the porous film tend to decrease the resistance and so increase the risk of corrosion, which may then be concentrated on relatively small areas.

The practical importance of the many fundamental investigations into the formation of the oxide film has been well shown by Champion<sup>14</sup> who bases predictions as to behaviour in service on the form of corrosion-time curves derived from properly conducted tests. Neglecting the initial period when the logarithmic law operates, the exponential curves are shown to be valid for the majority of cases, the exceptions being those when the conditions are sufficiently severe to prevent film formation (e.g., strong hydrochloric acid) or when stress is present to accelerate attack. He concludes that corrosion tests must be so designed and recorded as to allow extrapolation of curves based on the results of relatively short time exposures to the conditions required. Observations made in the initial stages of a

test, without reference to the form of the curve, give a misleading pessimistic forecast of the likely service life and it is preferable to expose a number of specimens, withdrawing test pieces at suitable intervals to build up the curves.

#### Resistance to Different Forms of Corrosion

The forms of corrosion which may occur either singly or combined are — general, pitting, intercrystalline and galvanic.

General corrosion of the metal results when the oxide film is uniformly dissolved from the surface and the severity of the attack varies from mild discolouration to rapid solution such as occurs with the strong acids and alkalis.

Champion<sup>15</sup> has shown that for reasonably homogeneous aluminium-base materials the depth of corrosion is independent of initial metal thickness and that the corrosion-time curves can be used to estimate the initial thickness of metal necessary to give the required service life without a significant reduction in mechanical strength occurring. This method of approach, based on accurately determined curves obeying an accepted law, allows a lower overall factor of safety to be introduced by the designer than is possible for metals which give linear corrosion-time curves. Such calculations are valid for general corrosion but not for conditions giving stress corrosion.

Pitting is the result of localised attack due to the presence of foreign metals at the surface, especially copper, iron or nickel; discontinuity in the oxide film; imperfections in the original surface; internal stresses; or conditions external to the metal such as differential-aeration cell action. Pits may not be particularly troublesome in structural material of adequate thickness, but they determine the useful life of such items as roofing sheets, and gas or liquid containers in the chemical and food industries. According to Champion<sup>16</sup> the frequency and depth of pitting conform to a normal

<sup>13</sup> Britton and Evans, *J. Chem. Soc.*, 1930, ii, p. 1773.

<sup>14</sup> Champion, *Met. Ind.*, **72**, pp. 440–442, 444 (May 28, 1948). **72**, pp. 463–464 (June 4, 1948).

<sup>15</sup> Champion, *Met. Ind.*, **74**, pp. 7–9, 13 (Jan. 7, 1949).

<sup>16</sup> Champion, *J. Inst. Met.*, 1943, **69**, 47. *Met. Ind.*, 1943, **62**, 178, 202.



probability distribution and hence deep pits must occasionally occur, although the risk of perforation is very small as the thickness of the aluminium is increased above the minimum value corresponding to the ultimate corrosion.

The risk of failure by pitting is seen to be small by considering the many aluminium utensils in constant daily use, and also by the success of roofing sheet over many years. Fig. 3 shows an interesting sample of aluminium sheet (99% Al.) taken from a Düsseldorf Bank roof after some 34 years service. It was installed in 1912 and removed in 1946 after the building had been damaged during an air raid some time prior to that date. The surface was rough with some pitting from both sides but complete perforation of the sheet which was about 0.06 in. thick was not observed.

Intercrystalline attack may take place when certain of the alloys are in such a condition as to show an increased tendency to corrode at the grain boundaries. The heat-treatable alloys, especially those containing copper, are liable to this form of attack when they are in the soft or annealed condition or after precipitation treatment. The higher magnesium ranges of the aluminium-magnesium alloys are also susceptible to intercrystalline failure if they have been wrongly treated during production, but actual instances are rare. Intercrystalline attack may be accelerated by tensile stress but stress corrosion failures are not necessarily intercrystalline. Again, the occurrence of stress corrosion is uncommon and can be prevented by avoiding incorrect heat-treatment sequences.

Galvanic corrosion takes place when dissimilar metals are connected in the presence of an electrolyte and when aluminium forms part of such a couple it usually suffers preferentially, except when the other metal is zinc or magnesium. Little risk is encountered with iron or ordinary steel, or by contact with chromium steels. The solution potentials existing between aluminium or its alloys and steel do not exceed 0.25 v. and accelerated attack is therefore expected only under the most severe conditions. Contact with copper and copper-rich alloys, nickel and nickel alloys, and the precious metals, should be avoided but lead does not have any appreciable effect.

Galvanic action is readily prevented by insulating the two metals concerned. This may take the form of a good paint film on both metals or the interposition of a suitable shim or washer, such as of rubber or water-proofed fibre, etc. It is less easy to prevent electrolytic attack when it results from the deposition of the second metal on to the aluminium surface by for example, a liquid containing copper salts in solution. The design of the assembly should be such that discharge of liquids containing heavy metal salts onto aluminium surfaces does not occur.

#### Protective Measures

The protection required, in addition to the natural oxide film, must be selected according to the types of

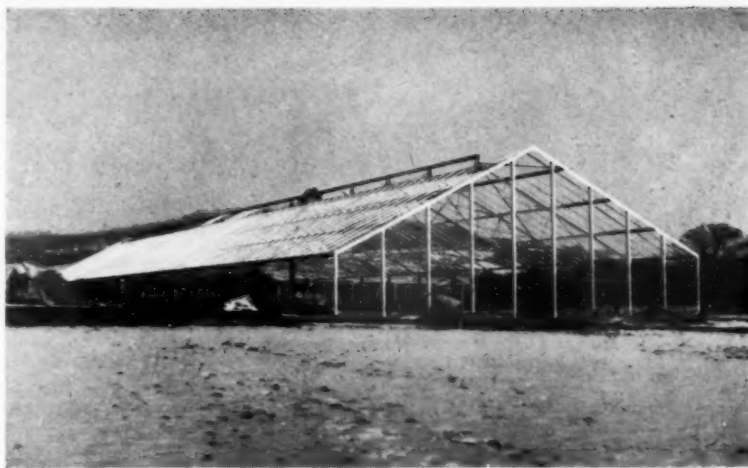


Fig. 4.—Aluminium alloy greenhouse — typical of the large number of commercial glasshouses now in use and under construction.

alloy, the form of the material, and the environment. There are at present few specifications or codes of practice covering the classification of protective measures in relation to service conditions but data have been accumulated with a view to definite recommendations being prepared. One interesting classification was published in the report — "Aluminium Alloys for Naval Use" — wherein the aluminium alloys were divided into three groups according to their characteristics in relation to Admiralty requirements. In the first group are placed the non-heat-treatable alloys with maximum resistance to corrosion and which do not therefore rely on a protective paint film. In the second group are the alloys of similar or almost equal inherent corrosion resistance but which require heat-treatment, thus introducing a possible, though small element of risk if the heat-treatment operation is not carried out correctly or if the alloy has been re-heated to temperatures rendering it susceptible to attack. In the third group, are the alloys with lower inherent resistance to corrosion and which therefore require the maintenance of an adequate protective film such as a suitable system of paint coatings.

A rather similar classification has been proposed for building and structural applications, and related to the alloy groups are four types of service environment, namely, rural, urban, heavily polluted industrial and marine atmospheres, with the possibility of combinations of the first three and the last mentioned. Another grouping for building components and fittings used indoors would comprise dry conditions in houses, offices, and the like; moist atmospheres such as occur in certain workshops and factories (e.g., laundries or cotton mills); polluted conditions which may have to be treated as special cases (e.g., chemical works).

In many such classifications there are service conditions which allow suitably selected alloys to be used unprotected and others which require protection of even the pure metal. The application of a coating of paint or enamel; thickening the oxide film; electrodeposition; chemical treatment — all add to the cost and should therefore be specified only when the additional cost is fully justified. There have been many instances wherein the costs of painting an inferior material have proved



Fig. 5. Aluminium alloy fish boxes as used at many ports.

greater than the additional cost of a more suitable alloy. Often the conditions do not make protection necessary but æsthetic considerations demand painting or the application of an anodic film, and in such circumstances there may be a tendency to inefficient treatment resulting, for example, in a thin anodic film which might lead to pitting at the sites of any discontinuities. Paint or other organic finishes require suitable prepainting treatments in order to give adequate adhesion and these processes should be carried out with as much care for small items for indoor use as for outdoor or marine structures.

The various means of protection available may be briefly summarised as anodising and chemical oxidation; plating with a suitable combination of deposits; applying an appropriate series of paint coatings or lacquer, stoving enamel or the recently developed vitreous-type enamels; or cladding to give cathodic protection.

The use of anodic oxidation and electrodeposition is growing as knowledge of the methods increases and becomes more widely disseminated. The preparation of the first part of a British Standard covering the performance of anodised aluminium is almost completed and further work is in hand on the methods of testing and assessing corrosion.

Cladding a strong heat-treated alloy with pure aluminium or another suitable alloy is one of the most effective means of combating corrosion of the copper-containing materials but is applicable only to sheet, strip, and plate at present. Extruded sections clad with aluminium have been produced but are not entirely satisfactory as yet. Clad tubes have been used in the U.S.A. to a modest extent.

Consideration of painting is divided into two main parts, namely, pretreatment methods and priming coats. To the many procedures for preparing the surface for paint already available has been added the "Alocrom" process during the past few months and it has aroused justifiable interest<sup>17</sup>. The production of priming paints which do not require prior treatment of the metal is most attractive and a recent American development indicates the possibilities<sup>18</sup>. A primer consisting of zinc

chromate in a vinyl-butyrate resin and thinned with a solution of isopropyl and butyl alcohols plus phosphoric acid is applied to sheet or strip which requires only to be degreased, the acid reacting to etch the metal and so provide a good surface for adhesion.

A recent British contribution<sup>19</sup> to the question of primers for aluminium-base materials shows that zinc chromate is the most suitable pigment but red iron oxide is very near to it in effectiveness. Primers containing red-lead are not suitable for aluminium as they probably deposit lead on the light metal to give an effective galvanic couple.

Mention must also be made of the vitreous-type enamels which have become available for several aluminium alloy groups. These enamels when finally developed may

well open up new fields for aluminium, especially castings, and trials are of great interest at present. The American types are basically lead silicate as also are most of those available here, for lead compounds constitute the readiest means of reducing the firing temperature required. A leadless enamel with a melting point between 500° and 600° C. shows promise and would be greatly preferable to the lead-bearing compositions for well known reasons.

In conclusion, it must be reiterated that the present state of knowledge of the resistance of aluminium or its alloys to corrosion is by no means unsatisfactory and rests on a broad basis of sound research and proved experience. Fundamentally the problem of protection is less serious, by far, than is the case with ferrous materials and the means of finishing available are—diverse, economical and suited to large scale application.

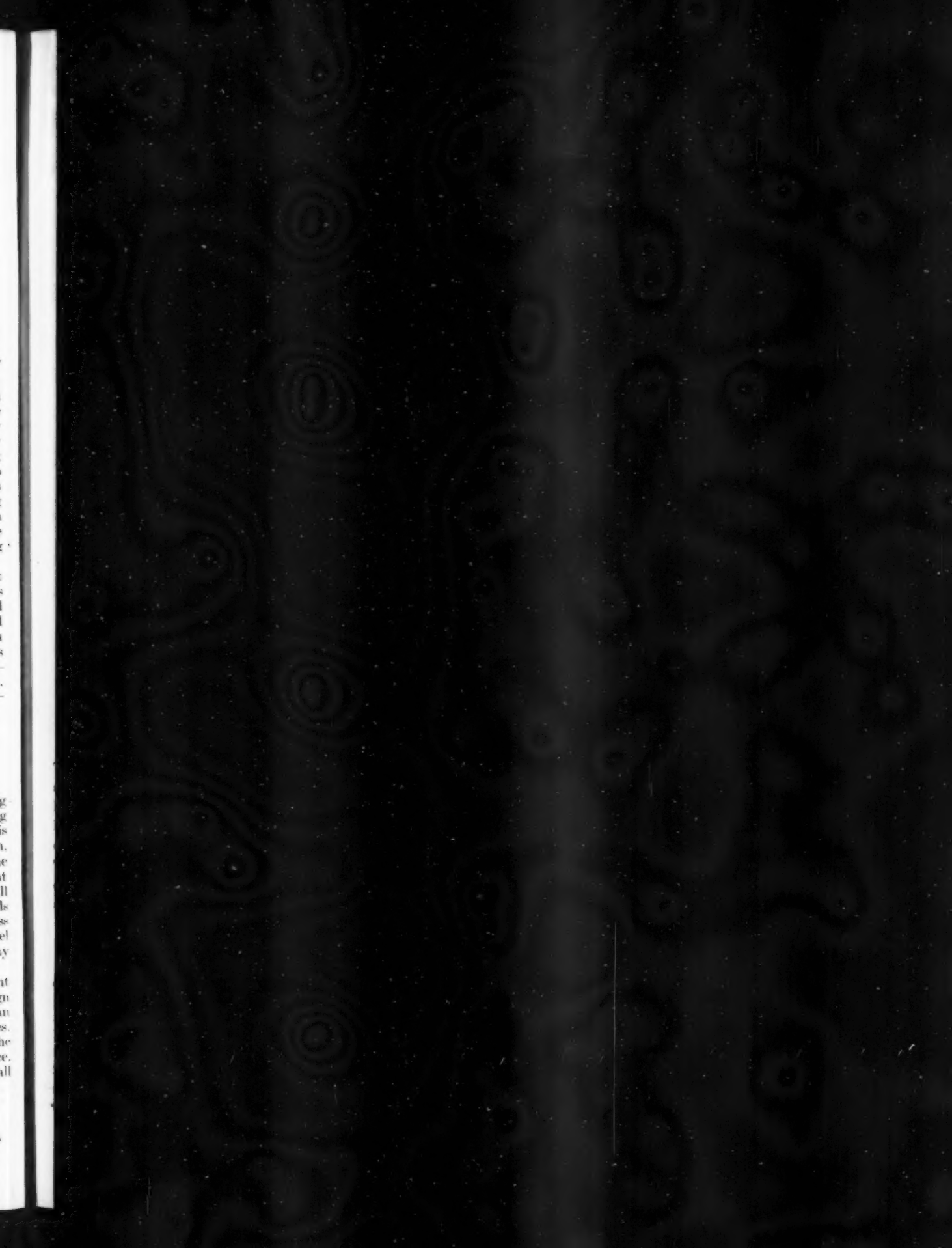
<sup>17</sup> Rigg and Skerry, *J. Inst. Met.*, 1948, **75** (2), 69–80.  
<sup>18</sup> Brit. Patent No. 580,688/9.

## Exhibition of Packing Materials

THE Institute of Packaging and the Printing, Packaging and Allied Trades' Research Association are collaborating with the Council of Industrial Design in arranging this exhibition at Murray House, Petty France, London, S.W.1, from May 3rd to 31st, 1949. It will show some of the more interesting packaging materials in current use as well as recent developments. Exhibits will include packages illustrating the use of new materials and interesting production techniques, or which possess some unusual design feature. Manufacturers who feel they have products suitable for inclusion in this display should write to the Council of Industrial Design.

The exhibition is the second in a series on different subjects organised by the Council of Industrial Design to assist designers in their day to day practice and as an information service to production and sales executives. The exhibitions are selective; they are not open to the general public and there is no charge for stand space. The area of the Council's Murray House Exhibition Hall is approximately 1,200 sq. ft.

<sup>17</sup> "Alocrom", *Light Metals*, Feb., 1949, pp. 71–77.  
<sup>18</sup> C. St. John, "Iron Age", 15 Jan., 1949, pp. 42–45.







# Aluminium... for Bridgebuilding



The properties of aluminium alloys provide the structural engineer with the many advantages of a light-weight metal, strong and extremely durable, that lends itself to easy fabrication with the normal engineering tools and equipment.

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## British Aluminium

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*The general contractors were Messrs. Head Wrightson Light Alloy Structures Ltd.*

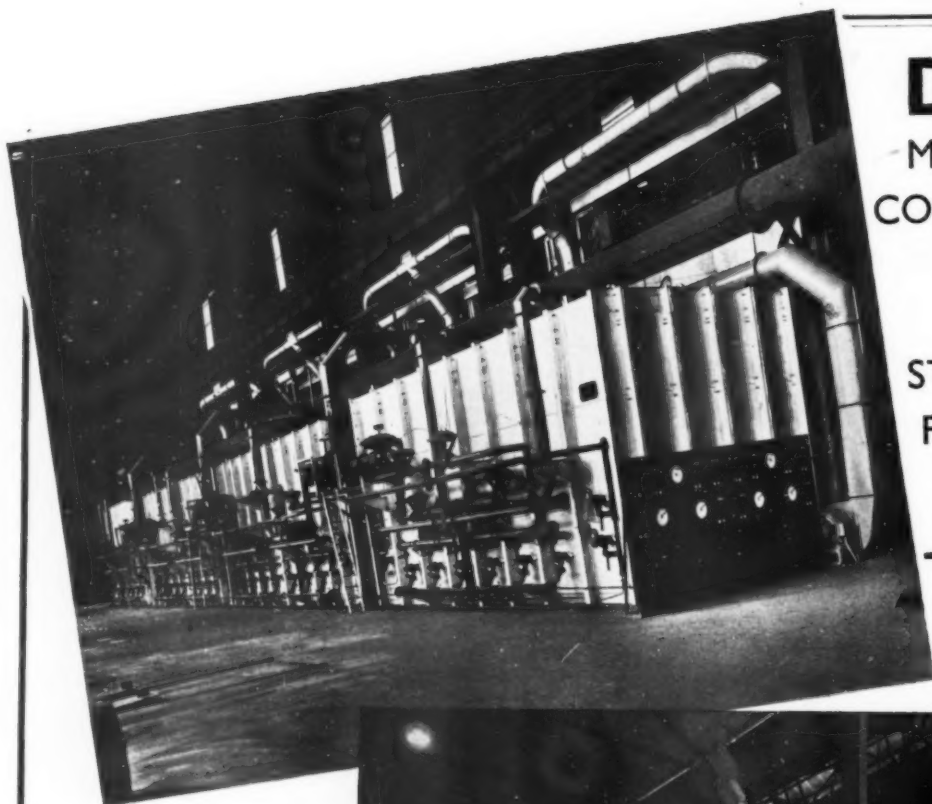
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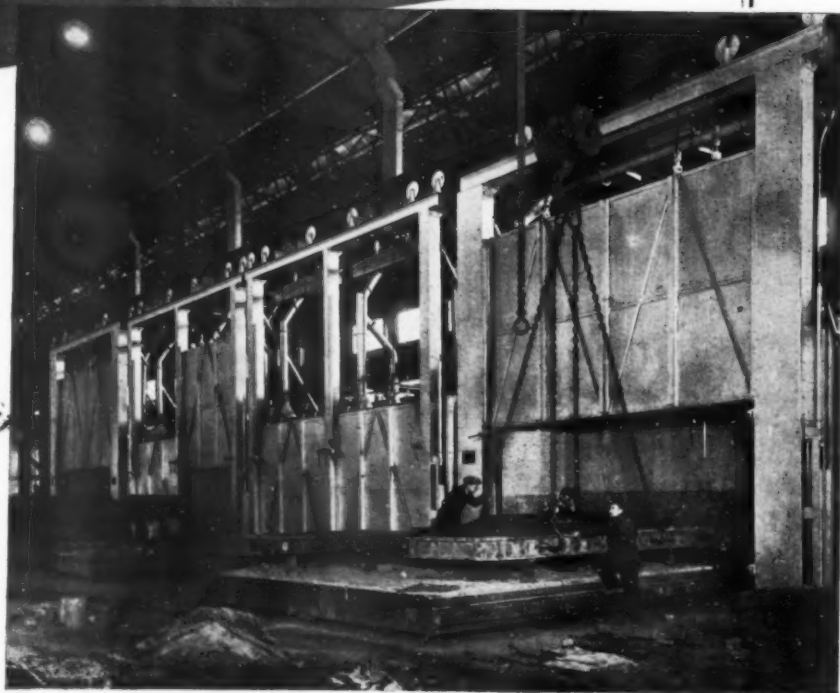


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## LIGHT ALLOY **forging** **on a Davy-United Press**

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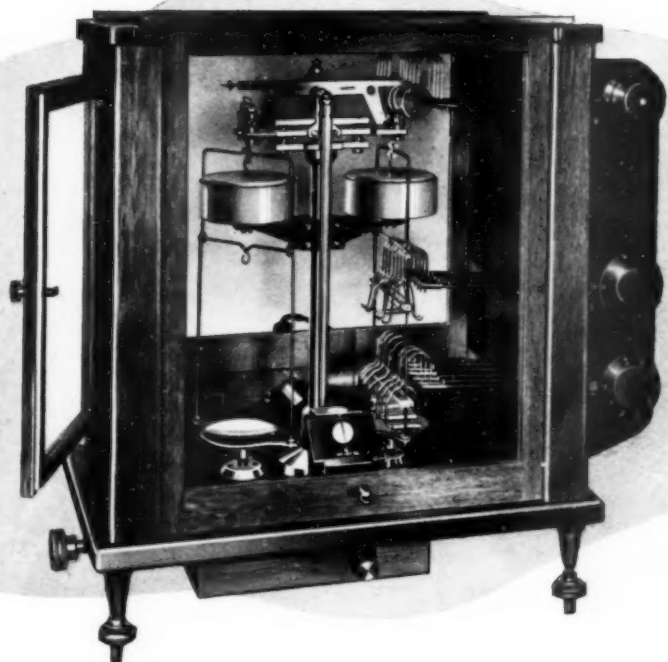
Three typical Davy-United presses for light alloy forgings are seen in this photograph showing, left to right, presses of 2,000 tons, 1,000 tons and 1,000 tons power respectively. The latter press also has an additional upsetting cylinder of 1,000 tons power. These presses, installed in the Distington Works of High Duty Alloys Ltd., have been used for pre-forming and dummie blanks for the manufacture of cylinder barrels, crankcases and other similar items, before final stamping.

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# Aluminium Sheet Development in Wales

## The Rogerstone Plant of Northern Aluminium Company Ltd.

*An enterprise conceived during the crisis year of 1939, which grew apace during the war and which now produces over a quarter of Britain's total output of aluminium sheet and extruded products, is Northern Aluminium Company's plant at Rogerstone in the Ebbw Valley. It now provides work for 5,000 people and is making a substantial contribution to Britain's economic progress. The development of this enterprise is briefly described.*

THE development of aluminium sheet production in South Wales — about which comparatively little has been written — dates from 1939 when the re-armament programme was gathering momentum in the darkening months of international crisis. Material was urgently needed for aircraft, in the design and construction of which aluminium alloys had replaced timber and fabric. Pursuing its policy of locating industry in what were then regarded as distressed areas, the Government chose the site at Rogerstone on which to make the vital material. Rogerstone had gas, electricity and water services, was near the main railway lines and to the large docks of the Bristol Channel. Labour, too, was available. Incidentally the site had an interesting industrial history, for it was in the year 1772 that a copper works was started by the Royal Mint Company among the ruins of a twelfth-century castle. Later it became a steel and tinplate works and was subsequently taken over by Guest, Keen and Nettlefolds to produce rod, wire and nails. Between the wars, however, the works fell into disuse.

Northern Aluminium Company, who were then manufacturing at Banbury almost half of the aircrafts' requirements of aluminium sheet, accepted the Government's invitation to erect and equip the Rogerstone Works. Excavation was started in August, 1939, and foundations laid for a factory to produce 500 tons of material per month. Within two months war was declared; the Company received instructions to proceed with all possible speed and to treble the capacity of the plant. The layout was replanned and a 3-stand tandem cold rolling mill was ordered, the largest of its kind outside America. Machines were ordered, workers engaged and engineers, technicians and administrative officers worked overtime. Forty local men were sent to Banbury for a course of instruction. Difficulties were encountered; because of the outbreak of war labour supplies had shrunk, younger men had joined the Services and older workmen had been absorbed by existing industries in the area. However, in spite of the set-backs, bottlenecks and difficulties in obtaining machinery, the work proceeded so rapidly that on January 9, 1940, only 17 weeks after operations had begun, the first ingot was cast from the melting shop.

On May 1, the first sheet was rolled from the mills. Thereafter, the expansion of the works was rapid and continuous and by December, 1941, 5,500 men and women were employed. Of the men, 250 had been trained at Banbury and returned to Rogerstone to give instruction in turn to new employees. Further expansion took place during 1942 and 1943 until a peak employment figure of 8,000 — more than half of them women — was reached and a total output of nearly

4,500 tons per month of aluminium sheet, extrusions and a large variety of other products was being recorded. This represented a fifth of the total output of Britain. From this material were built thousands of Spitfires, Lancasters and Halifax aircraft during the war years.

The sudden ending of the war brought an immediate slump in output. Uncompleted contracts were cancelled, the number of new orders fell heavily. It was necessary to discharge large numbers of employees. A period of reconstruction followed, during which the resources of the plant were adapted to peace-time production. The demand changed from aircraft parts to aluminium houses. The demand for steel and timber to meet the needs of the exporting industries could not be satisfied and the resulting shortages in these materials created a demand for substitutes and these were found in aluminium. Research and development departments concentrated on the wider use of these light alloys and in a comparatively short time their potentialities were widely appreciated and it was soon realised that the demand for aluminium products would exceed expectations. At first it was feared that at least six of the ten extrusion presses at Rogerstone would be out of commission. In fact, nine of these presses have been working and there are sufficient orders on hand to keep them in operation for many months.

When in 1946, the Government decided to dispose of plants such as Rogerstone, which had been operated on a rental basis, Northern Aluminium Company decided to buy the works. In the past two years the production methods have been reorganised and streamlined to meet the more competitive conditions of peace-time, and this re-organisation has already resulted in a considerable increase in productivity. This is emphasised by the comparison of the peak war-time production of 4,500 tons per month with over 8,000 employees, with the present output of 4,000 tons per month with fewer than 5,000 employees.

A Joint Production Committee, one of the first to be set up in the country, was introduced in 1942 and continues to function successfully. A bonus system in force has been an added incentive to employees to give of their best. Last month this production bonus enabled employees to take home an extra £2 16s. 6d. at the end of one week, the highest figure reached since the firm started. Close collaboration exists between workers and management and, recently, each employee was given a letter from the Managing-Director of the Company which explained in simple terms the financial organisation of the firm. This personal letter explained where the money went: Of every £, 8s. 7d. was used to purchase the raw materials — the aluminium ingot; 6s. 2½d. was taken by wages, salaries, holiday-pay and health

insurance; 3s. 2d. by fuel, power, stores, repairs and maintenance, etc.; 1s. by taxation; 4d. by depreciation; 3½d. by dividends to shareholders; and 5d. by a reserve set aside for reinvestment in the business.

Over thirty per cent. of the total output of the Rogerstone Works is exported while a large part of the balance goes abroad indirectly in the form of motor-cars, buses and parts of machines. Sufficient dollars are earned in this way from the United States and Canada and other dollar areas to more than pay for the raw material imported from Canada. The aluminium is obtained from Canada in the form of ingot and rolling slabs and purchased by the Government and sold to the Company. It is noteworthy also, that with the exception of a few technicians and administrative staff, all the labour, consisting at present of 4,500 men and 450 women, is obtained locally.

Of the future, the Works Manager, Mr. E. S. Anderson, who has seen the site transformed from a collection of rusty and derelict buildings to the largest plant of its kind in Europe, says: "There is, we think, a bright future for the production of aluminium sheet. During the war output of aluminium increased four- to five-fold. When hostilities ceased we were faced with the problem of whether there would be sufficient demand for our

products for peace-time uses. There is a colossal market for corrugated sheets, chiefly abroad. The market for extrusion products, angles, channels, structural, decorative and so on, is not quite so certain, but for the time being at least we have sufficient orders to keep up our present employment for many months."

That the Company has confidence in the future is indicated by the fact that extensions are in progress to make the plant the largest of its kind in the world outside the United States. On part of the hundred-acre site now owned by the Company a main sequence of hot rolling equipment a third of a mile long is being laid out to provide a continuous aluminium strip mill. By 1951 Rogerstone will be to the aluminium industry what Ebbw Vale is to-day and Margam will be to-morrow to the steel industry of the United Kingdom. An annual output of 50,000 tons of aluminium sheet products is planned and if markets are available further expansion will be possible to enable output to be increased to 150,000 tons a year. The size of this project will be appreciated when it is remembered that, at the peak of war-time production, the greatest combined annual output of aluminium sheet from all plants in the United Kingdom was approximately 100,000 tons. This new development represents an expenditure of over £3,000,000.

### Scaffold Tubing in Aluminium Alloy

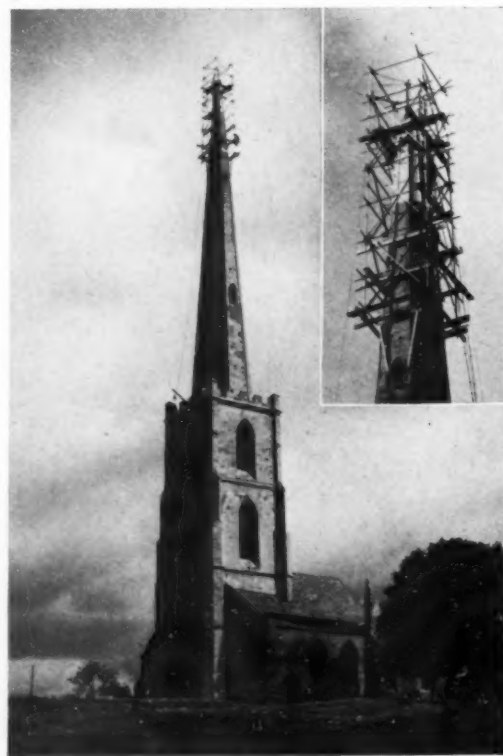
ALTHOUGH ten years ago the potential advantages of using aluminium-alloy tubes for scaffolding were as obvious as they are to-day, price ruled them out. The situation has changed since then, due to the fact that the cost of aluminium tubing, suitable for this purpose, has been reduced, whereas steel tubing has increased considerably in price.

In 1945 Northern Aluminium Co., Ltd. carried out tests to determine the suitability of aluminium-alloy tubing for this purpose, the results of which were so encouraging that the development of this application was undertaken. The practical advantages were then considered to justify the initial cost, which was twice as much as that of steel. Events have proved the decision to have been the right one, since, following the initial efforts of the Company in 1946 to interest the trade, nearly 10 million ft. of Noral scaffold tubing have been sold. With additional sales by other companies now manufacturing tubing for this purpose, there is ample evidence that the initial tests proved of great service to both producers and users. To-day aluminium-alloy scaffold tubing is firmly established on its own merits, and a recently published brochure, by Northern Aluminium Co., Ltd., gives the full technical specification of Noral scaffold tubes.

Weighing only about one-third as much as steel, aluminium scaffold tubes are easier to handle, substantially reducing the time for erection and dismantling, and reducing transport cost by nearly two-thirds. Since the weight of the tubing used is normally an important part of the load on a scaffold structure, light-alloy tubes are less severely stressed than steel. Being as strong as steel and having greater resilience, light-alloy tubes have an extra margin of safety.

Aluminium-alloy scaffold tubes withstand corrosive attack and are always clean to handle; no descaling, painting or other maintenance attention is required. Standard couplers and fittings are used and no change in scaffolding practice is necessary. Readers will have

noted the growing use of light-alloy scaffolding in almost every town in Britain, but a particularly appropriate application is shown in the accompanying illustration.



Light alloy scaffolding erected by Messrs. V. G. Morris, Ltd., to effect repairs to the spire of St. Andrews' Church, Worcester.



# Making Rings of Stainless Steel

By R. Groves

*There are many ways of making rings in stainless steel, the choice of method being governed by the properties required and by economic factors. In this article, the author describes a method of manufacture in which two half-rings are joined by pressure welding, and discusses the advantage and limitations of the process.*

**T**HERE are various methods by which stainless steel rings can be manufactured, and the choice among them depends largely on the economics of the job. The modern tendency, as will be seen later, is in the direction of pressure welding, but before outlining the technique employed in this latest development, the alternative methods will be indicated. Of these, the first is, perhaps, the most widely employed. This comprises the production of a ring entirely without seams from a suitable disc of the steel, which is pierced and subsequently rolled on a mandrel to the approximate size. Certainly this gives a ring with very good mechanical strength and physical properties, but there are drawbacks that must be taken into account.

## Disadvantages of Piercing

First of all, as soon as the rings exceed a small diameter, production by piercing involves a good deal of intricate workmanship and considerable handling. Secondly, it is only possible to use this method for parts of comparatively simple cross section, though by the application later of die forging, somewhat intricate forms can be made. For this reason another popular method comprises machine forging a round or square slug of the steel on flat dies to yield a disc of the desired dimensions, after which the disc is given its final form by die forging. For this technique the slug must be capable of being drawn down under the forging machine to the desired diameter and thickness without fracture or cracking. One drawback of this method is the high proportion of discard material resulting from the large amount that has to be punched out of the central portion of the slug.

A third process consists of butt welding suitably prepared material by the flash method so as to form a ring, which is afterwards given the necessary form by die forging. This process is mainly confined to rings of somewhat thin cross section. A variation on this is to roll the ring to the required dimensions, and afterwards weld it manually, before die forging to provide the required contour.

## Pressure Welding Technique

The object in developing the pressure welding technique, to be described, was to obtain greater facility in production, without too great a sacrifice of mechanical and physical properties. The basis of the method is the union of two semi-circular halves of the ring by two diametrically opposite pressure welds. In Fig. 1, the stages by which the ring is so formed are indicated. The heat required for welding may be obtained by the use of either oxy-acetylene flame heating or induction heating, but the oxy-acetylene flame appears at the moment to be the more popular.

## Application of Pressure Welding

The economic importance of the new process is particularly in evidence when the required number of

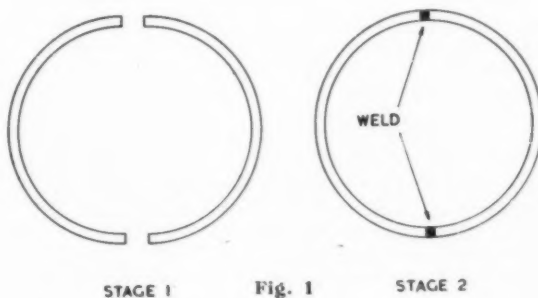
rings of given dimensions is not large enough to warrant a heavy outlay on dies and equipment. It is also metallurgically advantageous when the type of stainless steel used is one liable to crack at the rim of the forged disc, so that a heavy grinding cost has to be incurred. These factors must be carefully weighed against the actual cost of forming the rings by pressure welding.

In welding stainless steel rings by the pressure method, the first requirement is control of the welding temperature. This is most important, because, if the temperature is not high enough, the joint will be imperfect, while if it is too high, incipient fusion and oxidation at the grain boundaries may occur. It has been found in practice that the best welding temperature for the chromium nickel stainless steels, of the 18-8 austenitic type, is in the region of 1,200° C. for a specific amount of upsetting. The actual pressure employed in making the weld ranges from 3,000 to 6,000 lb./sq. in., but it is found that if the welding temperature is correct, variations of welding pressure within this range have no appreciable influence on the result.

## Preparing the Rings

The first step in making rings by the pressure welding method is to ensure that the ends of the stock semi-circular pieces are thoroughly clean and perfectly flat. The end faces of the material may be either mechanically ground or machined smooth. The degree to which the rings are upset at the joint depends on the amount of total shortening, and it has been found that a total shortening amounting to  $\frac{1}{8}$  of the thickness is adequate as long as the weld faces remain closed throughout the welding operation. With the larger and thicker rings, it is sometimes found that the expansion caused by heat leads to an opening up of the outer edges of the cross section in advance of the attainment of plasticity. As a result, these faces become oxidized, and consequently there will be imperfect union.

The mechanical properties obtained from the welds made in this way prove to be much superior when the rings are forged, because the hot working has the effect of refining the grain, and in addition rectifies the fibres of the grain flow at the point of upsetting, thus breaking



up the particles of oxide at the weld interface. Moreover, the very act of forging results in the speedy detection of any unsound or imperfect weld, because the deformation involved readily exposes weakness at this point.

The reader may wonder why the rings are not formed by a single pressure weld of a section rolled to a circular shape. The answer is that the surfaces to be united could not be made to give the close contact desired. The bending moment or resultant causes the welding faces to be opened up, so that they oxidize too severely on their surfaces. The method earlier outlined of making two pressure welds on semi-circular sections made the advance preparation of the parts much simpler, because the faces of the welds could be quickly and easily ground and cleaned.

#### Difficulties in Pressure Welding

It must not be imagined, however, that there are no troubles to be overcome in pressure welding. In the first place, it is still not easy to keep the two sets of welding faces in close contact during the heating-up period. There is a variation in the thermal expansion of the metal at different points because of the difference in temperature at different points of the ring section, and this is liable to cause the weld faces to draw away from one another. This tendency is increased by the degree of side thrust set up by the load.

A method whereby this difficulty was overcome is indicated in Fig. 2. This is termed the compensating grind. The principle is that the separate semi-circles constituting the ring are elastically expanded to diameters somewhat greater than required at the faces of the welds, followed by grinding. When the correct starting end pressure is applied to these rings, the bending moment results in the rings coming into close contact.

Another trouble experienced is uneven expansion of the cross section under heat when the rings are of considerable thickness. This leads to an opening up of the weld faces at the surfaces of the sections to be welded. To overcome this, modifications are made to the heating cycle, the rate of heating, and the amount of heat, so as to cause a thermal expansion in one direction to compensate for and combat the expansion in the other.

It need not be said that the greater the final pressure, the lower will be the temperature at which the steel will be plastically deformed. Advantage is taken of this by making the original end pressure sufficiently great to deform the material plastically at temperatures within the range 700-760° C., so as to seal up any slight opening that arises during heating. To ensure close contact between the surfaces to be united, about 25% of the entire shortening is taken up at this juncture. The employment of a closed hydraulic system enables the pressure to be reduced gradually in proportion as the piece gives, as a result of increasing temperature. As soon as the pressure is low enough for the attainment of the correct welding condition, the concluding upset pressure is applied.

#### Heating Cycles and Gas Flow

In this process, it is essential not to rely upon heating cycles determined previously for other forms of ring manufacture. Each job must be taken on its merits and its own heating cycle determined. Correct flow of gas is best attained when gas pressure gauges are attached to the torch; and when the torch needle valves are in

the wide open position, the injector serves as a critical orifice flowmeter. Delivery pressure regulators in the principal gas line are adjusted to keep the line pressures somewhat higher than operating pressures, while station regulators are located as near as possible to the torch, so as to keep up correct operating pressure at the torch. This technique reduces the amount of operating pressure variation, while falls in line pressure exercise no influence on the flow of gas except when the main line pressure falls below the operating pressure. A larger gas flow serves to increase the temperature gradient over the area to be welded.

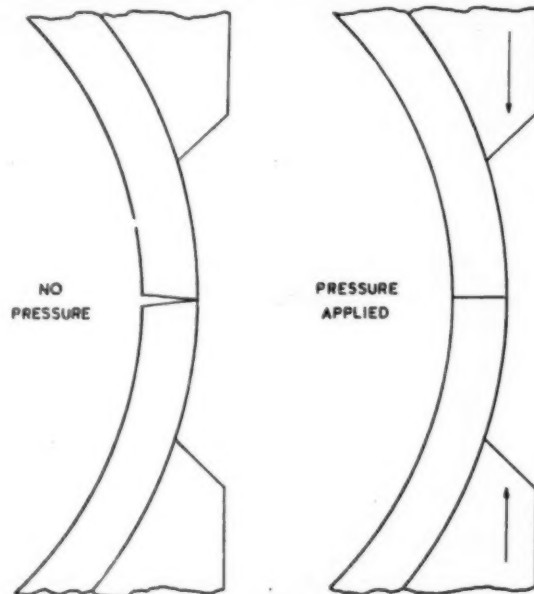


Fig. 2

The gas flow should be regulated so as to yield a cycle sufficiently swift to produce plastic deformation of the material and close up the faces of the weld at the earliest possible moment, but not so fast as to increase the temperature gradient or cause burning at the surface. The precise flow of gas is immaterial as long as it can be kept constant, but a sensitive meter is advisable because it makes reproduction of the conditions easier for each weld, and necessitates less attention.

#### Pressure Welding Equipment

The gas capacity must be adequate. The heating heads must be of a design capable of giving the right amount of heat input over the cross sectional area to be welded. Where there is a likelihood of severe thermal expansion leading to opening up of the weld faces, differential heat input may be called for. The heating heads must be constructed so as to prevent burning especially at corners, and should be in such a position that they do not make it difficult to take away the rings when completed.

The presses must be capable of gripping the rings firmly and with the precise amount of pressure required. Hydraulic systems are preferable because of the ease with which variation in pressure may be obtained. The presses must also be rigid enough to ensure that the semi-circular pieces are properly matched, and should have positive stops so that the welded rings are held to

accuracy of size. The dies must be made from a steel or other material capable of withstanding high temperatures; they must be correctly aligned, able to sustain the work, and to transfer pressure to the weld. Cooling by water is often adopted to prevent excessive expansion of the die, particularly when the heavier-section rings are being made.

Die holders for the bigger rings are sometimes furnished with a three-point contact and with adjustable contacts close to the welds. These enable the necessary modification to be made to surfaces closely fitting, and give maximum contact within the limits for bent half rings.

The torches are caused to oscillate over the weld so as to avoid excessive heating and burning at particular points. The extent of the oscillation is equivalent to the total shortening, and it is achieved either by hand or mechanically.

#### Defects and their Causes

Certain points must be watched if defective rings are to be avoided. The initial end pressure must not be too low, or fissures may form at the surface of the weld, consequent upon the opening of the weld when the

operation is in progress. Such fissures are sometimes found at the inner diameter, but this is not common. Much more common are fissures at the outer diameter and these arise mostly as a result of too great a bending moment, causing opening, which can be corrected by the method of compensating grind referred to earlier.

Defective welds may result from the presence of a film of oxide between the welding surfaces supposedly united. Such a film arises when the surfaces to be joined have not maintained the closest possible contact throughout the welding operation. High initial end pressure and take up of a proportion of the entire shortening under this high pressure alleviate this trouble.

Burning is found to be caused by an excessive heating rate, which causes the surface to become badly overheated and its structural condition spoiled long before the centre has reached the correct welding temperature. Burning almost always causes the weld to open during later forging. Careful control of the heating rate can prevent this. Low ductility of the weld may result either from too low a welding temperature, or from the presence of oxidation at the weld surfaces.

# The Use of Inhibitors for Controlling Metal Corrosion

## Part III—Chromate and Dichromate Inhibitors

By G. T. Colegate, B.Sc., A.I.M

**C**HROMATES are widely used as inhibitors, mainly on account of the relatively low concentrations that are needed to prevent the attack of waters on iron and steel. As pointed out previously, they are regarded as anodic inhibitors and are, therefore, potentially dangerous if used in too low a concentration. However, since the effective concentration is invariably low, it is normally economically possible to maintain the amount of chromate in the solution at many times the minimum figure.

Chromates are gradually used up in maintaining protection of ferrous metals and constant additions must be made to keep the concentration above the required minimum.

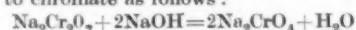
Although chromates are usually regarded as anodic inhibitors they are considered by some to act primarily as passivators. That is to say the chromate ions are assumed to form an adsorbed layer on the surface of the metal, sharing electrons from the atoms of iron at the surface and thus satisfying secondary valency forces, rather than forming an insoluble chromate or iron-chromium complex compound in close contact with the surface as required if it were acting as an anodic inhibitor.

Darrin,<sup>1</sup> who has carried out extensive research work on the use of chromates as inhibitors, considers that the experimental evidence points to a dual character in the mechanism of chromate inhibition of the corrosion of steel. He considers that in the first place passivation occurs more or less instantaneously, this being followed by the gradual building up of a protective film which continues to develop for one to three months, after which it becomes stabilised. As will be shown later, the consumption of chromate during the first few months exposure is considerable, though after that the amount required to maintain passivity is relatively small. During the film formation stage of the process, if the chromate concentration is not maintained sufficiently high, especially in the presence of chlorides, there is a considerable risk of localised corrosion taking place.

#### Chromates or Dichromates

Although sodium chromate is the compound frequently referred to when speaking of chromate inhibitors, the potassium salt and the sodium and potassium dichromates are equally satisfactory as inhibitors. The chro-

mates are more expensive than the dichromates, but on the other hand, in using the latter it is necessary to add caustic soda to ensure conversion to chromate as follows:



The dichromate is normally purchased as  $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$  and in this form, one pound is equivalent to about 9/10 lb. of chromate and is, moreover, cheaper. In small systems this is not an important point but in large ones, the saving of money justifies the extra trouble in making the caustic soda additions.

The choice between dichromate and chromate may sometimes be decided by the acidic or basic nature of the medium to which it is intended to add it. For example, in use with brines or natural waters, chromates may be added to acidic ones and dichromates to basic ones, thus minimising the amount of alkali or acid which will have to be added subsequently to bring the medium to neutrality.

#### Evaporative Cooling Devices

In relatively large installations such as power stations, etc., it is usual to use some form of evaporative device for cooling the water from heat exchangers, the major part of the cooling

<sup>1</sup> Darrin, *Ind. Eng. Chem.*, 1946, **38**, 4, 373



being brought about by the evaporation of a portion of the water. There are, of course, a large number of different types of equipment for this purpose, including sprayponds, cooling towers and condensers, but the general principle is the same in each case and so is the problem of chromate addition. Unlike the closed type of cooling system such as used on a motor car, in which, as will be pointed out below, the quantity of chromate used is so small that its actual concentration has little economic significance, the concentration of chromate used in the open type of cooler is of considerable importance in affecting the economics of the cooling. This is for several reasons. First, it is necessary, in order to avoid building up too great a concentration of solids in the cooling water to run off some of it to waste from time to time, and this naturally takes chromate with it so that a higher concentration than is necessary means excessive waste. Secondly, the volume of water in these systems is always very much greater than in the closed systems, requiring correspondingly more chromate. Thirdly, the systems are expensive and contain in most cases a considerable area of metal, generally steel, but occasionally aluminium, so that it is essential to make sure that they are effectively protected.

The make-up water for such systems should of course be as pure as is reasonably feasible, and should be as low as possible in chloride since, as explained above, chlorides appreciably reduce the effectiveness of the chromate. The concentration of chromate required will depend on the area of metal in the system, and the chloride content of the water, but in many cases it is round about one-twentieth of one per cent. The most practical way of determining the minimum safe concentration in a given case is by trial and error, starting with say, a concentration of 0.15% in order to ensure the formation of a protective film and gradually reducing this until it becomes clear that the amount of chromate present is just sufficient to ensure protection of the system. In order to be on the safe side the working concentration should be fixed at about 50% in excess of the minimum found.

In the case of large systems such as the ones being discussed, it is usual to maintain the pH value of the water slightly on the alkaline side of neutrality, between say pH 7.5 and 9.0.

The rate of chromate replacement for a given chloride content depends on a number of factors. First, it quite

plainly depends on the rate of draw-off. Secondly, a certain amount will be used up in oxidising impurities with which it comes into contact, these depending mainly on the source of the water used for make up. Thirdly, the amount required will vary with the concentration being maintained as Fig. 1.—Accumulative consumption of sodium chromate per 1,000 sq. ft. in water containing 10 p. p. m. sodium chloride.<sup>2</sup>

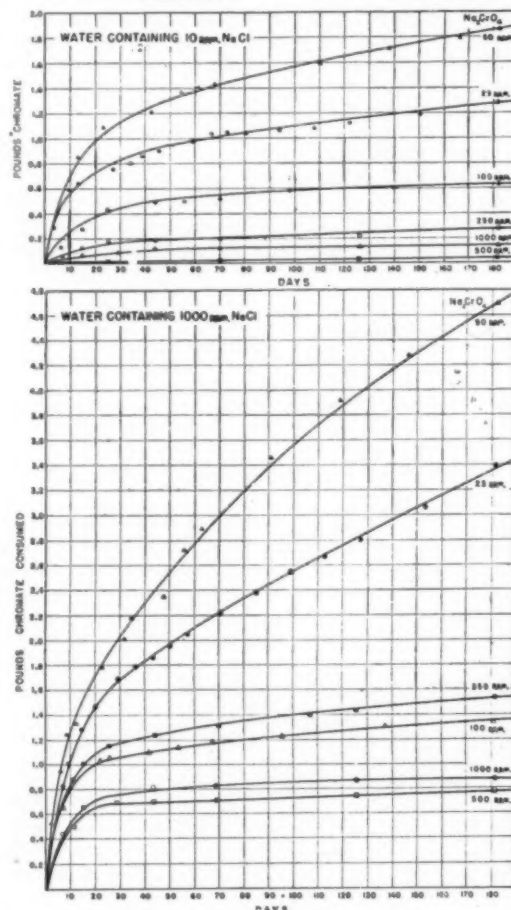


Fig. 2.—Accumulative consumption of sodium chromate per 1,000 sq. ft. in water containing 1,000 p. p. m. sodium chloride.<sup>2</sup>

indicated below. Fourthly, the daily amount required falls off quite rapidly with time, reaching a stabilised amount usually after about one to two months. The rate of additions cannot be accurately worked out beforehand, and is best determined by trial. However, the curves of Figs. 1 and 2 which are discussed below give a good guide to what is likely to be required. The presence of existing rust on iron surfaces also necessitates the use of a higher chromate concentration.

## Engine Cooling Systems

The use of inhibitors in the water jackets of engines is desirable for two reasons. In the first place, corrosion in such systems may be rapid and lead to perforation of the jacket wall, or partial blocking of inlets or outlets, and, secondly, the greater the amount of corrosion that takes place, the greater the quantity of scale and rust deposited on the metal surface, such

deposition seriously interfering with the transfer of heat and reducing the efficiency of the cooling system.

In those instances where the water in the cooling system is recirculated, as is generally the case, the addition of inhibitors, particularly chromates, can usually be justified on economic grounds. When the water is not recirculated, however, the use of inhibitors is usually out of the question, as, for example, where sea water is used as a coolant in ships. The quantity of inhibitor required will naturally vary somewhat with the nature of the cooling water, but in an ordinary car radiator half-an-ounce of sodium chromate per gallon of the capacity of the system will ensure satisfactory results with most waters. It is obviously desirable to choose, as far as possible, a water which is relatively non-corrosive in order to give the chromate the maximum chance of being fully effective, though in most cases there is no choice in the matter. However, in the case of engines where there is known to be very little loss by evaporation, and therefore little likelihood of subsequent contamination in making up, it is worthwhile making an effort to fill the system with a soft, neutral water—rain water for example. In cases where such a water can be used and where it is known that there is no risk of future additions of appreciable quantities of a different type of water,



the concentration of sodium chromate can be safely reduced to a fifth of the figure mentioned above. It is the practice in some cases to use distilled water in cooling systems, and in this case a concentration of a tenth of one per cent. of chromate is adequate to ensure effective inhibition of corrosion in the system, in fact much lower concentrations could be used satisfactorily, but from the practical point of view are more difficult to control. By using a higher concentration than is theoretically necessary analytical checks need to be made less frequently and the quantities involved in any case are so small that the additional expense of using, say, five times the theoretical amount is of no importance.

A dosage of chromate is usually sufficient to last about a year, provided evaporation loss and leakage loss are relatively small, but after that period the whole system should be drained and refilled. Cooling systems, for example of motor cars, frequently include a copper radiator and various brass parts. A concentration of a half-ounce per gallon of sodium chromate is adequate to ensure the absence of serious galvanic corrosion between these metals and the ferrous parts of the system.

It is not usual to add a chromate inhibitor to cooling systems containing anti-freeze solutions as some of these react with the chromate and destroy its effectiveness or else, in the case of the ones consisting mainly of calcium chloride, the chromate is ineffective at the temperature of operation.

#### Chromate Consumption

The Mutual Chemical Co.<sup>2</sup> of America have worked out in detail the amount of chromate consumed in protecting iron in waters containing various quantities of chloride. Some of this information is reproduced in Figs. 1 and 2 showing the consumption per 1,000 square feet of iron in waters with a chloride concentration of 10 and 1,000 parts of sodium chloride per million. In each case it is seen that the rate of consumption falls off with time and that in the first 1-2 months it is relatively high. On each graph are shown curves for a number of chromate concentrations from 50 to 1,000 parts per million, and it is clear that in each case the rate of consumption of chromate is highest at 50 parts per million and lowest at 500 parts per million. The curves only apply to one set of conditions, and if the conditions

in practice are more corrosive than those for which the curves were determined, due allowance must be made for the fact by introducing a suitable factor of safety. Such a factor of safety may be required for example if the temperature under consideration is higher than room temperature at which the curves were determined.

#### Chromates in Refrigerator Plants

The American Society of Refrigerating Engineers lays down various recommendations for combating corrosion in refrigerating plant using brine. For calcium chloride brine the concentration suggested is 100 lb. of sodium dichromate per 1,000 cubic ft. of brine, that is to say, about 0.16% by weight. Sufficient caustic soda is added to convert the dichromate to chromate, the amount required depending on whether or not the brine contains ammonia, and if so, in what amount. The quantity required for a neutral brine is about 27 lb. per 100 lb. of dichromate and proportionately less for ammoniacal ones, to which sufficient must be added to render them just alkaline to phenolphthalein.

The dichromate is best added all at once to the system by dissolving in warm water and adding slowly to the brine, but where it is desired to do so it may be hung in the system in a bag and allowed to dissolve gradually, a method that ensures good distribution. Replenishment of dichromate is made annually, the quantity added being half the original amount. In plants, the size of which merits it, a certain economy can be effected by determining the size of the addition required by chemical analysis.

With magnesium-calcium chloride brines and sodium chloride brines, twice the concentration mentioned above for calcium chloride should be used.

The effectiveness of the chromate additions to a system can be judged by exposing a clean steel specimen to the continuously aerated water for seven days, after which period there should be no appreciable corrosion.

Besides inorganic chromates, certain organic materials such sodium chrome glucosate have been successfully used in preventing the corrosion of iron and steel.

#### Use of Chromic Salts as Inhibitors

The possibility of using various metal salts as cathodic inhibitors was mentioned in the first article of this series. Chromic salts are among those which have been considered for this

purpose, and if effective they would be in the "safe" class of inhibitor, and would not, therefore, suffer from one of the disadvantages of chromates, namely that, used in too low a concentration, they may lead to intensification of attack instead of the diminution hoped for. Thornhill<sup>3</sup> investigated the possibilities of using additions of chrome alum to Cambridge tap water, which is a chalk water partially softened by base exchange and containing thirteen parts to a million of chloride. He also investigated the effect of chrome alum on the same water but somewhat enriched in carbon dioxide. Whereas zinc and manganese salts, which were also examined at the same time, furnished considerable protection to mild steel partially immersed in the water, the chromic compounds were not nearly so effective. The most effective concentrations for the latter was 0.001 molar, but in both higher and lower concentration the effectiveness of the additions fell off. As the concentration increased, the corroded areas spread progressively until the whole of the immersed portion of the specimen was covered with corrosion products. The greatest amount of attack was at the water line.

Thornhill also investigated the addition of chromium chloride to the water, since by adding chrome alum, an additional amount of corrosive substance in the form of potassium sulphate was added which may have influenced the results. In addition to the two waters mentioned above, the effect of chromic chloride additions to sodium chloride solutions was also investigated and the same thing was found to happen as with chrome alum additions, namely there was a concentration at which the corrosion was a minimum and above and below which the amount of the attack increased. There was severe attack at the water-line. In the sodium chloride solutions, at low chromium concentrations increase in the chloride ion concentration led to increase in the rate of attack, while with the higher chromium concentrations, the rate of attack was reduced as the chloride ion concentration increased.

From Thornhill's work it is clear that chromic salts are only effective in low concentrations. It seems unlikely that they will ever find industrial application as inhibitors for the corrosion of iron and steel, at any rate on a large scale, and certainly never on the scale on which chromates and dichromates are used.

<sup>2</sup> Mutual Chemical Co. of America, "Chromate corrosion inhibitors for internal combustion engines."

<sup>3</sup> Thornhill, *Ind. Eng. Chem.*, 1945, **37**, 8, 706

# Recent Developments in Materials Tools and Equipment

## A New Die Piercing and Polishing Machine

A PRECISION-built machine by Rudkin and Riley has been developed to meet the need for the piercing and polishing of carbide and other hard metal dies at high speed. Fine or coarse parallel bores, precise tapers, angles and radii are produced automatically on this machine.

Combining the features of three machines in one, this machine will produce any desired radius by a smooth radial reciprocating motion of the headstock and needle carriage, the lap in the polishing head being held firmly against the work by spring pressure. By disconnecting the reciprocating drive the headstock can be set at an angle to produce any desired taper or angle. Both the headstock and needle carriage can be locked in a central position to obtain fine or coarse parallel bores as desired. In addition, the headstock may be swung clear of the needle spindle and used as a manual polishing head.

The machine incorporates a special drive which imparts a smooth radial reciprocating motion to the headstock. This radial motion is obtained from a two-speed gear-box coupled to a reciprocating arm. The motion can be disengaged by the movement of a lever. The spindle is mounted in liberally rated ball races and driven by a keyed-on pulley on the end of the shaft.

The needle carriage is set to the correct height and has a transverse adjustment of  $2\frac{1}{2}$  in., while the whole needle carriage can be adjusted  $5\frac{1}{2}$  in. longitudinally. The upper portion of the needle carriage has been designed to swivel and thus, in conjunction with the headstock movement, obtain any desired angle. A 4 in. self-centring chuck with two sets of jaws is supplied but an 8 in. chuck and a stepped collet are also available.

The machine is driven by a  $\frac{1}{2}$ -h.p. motor mounted on a separate hinged base plate and can be adjusted for belt

tensioning. The recommended speed for the headstock spindle is 1,500-1,750 r.p.m. The needle chuck speed can be varied to 195, 225 or 262 r.p.m.

*A. C. Wickman, Ltd., Coventry,*

## Corrosion Protection during Storage

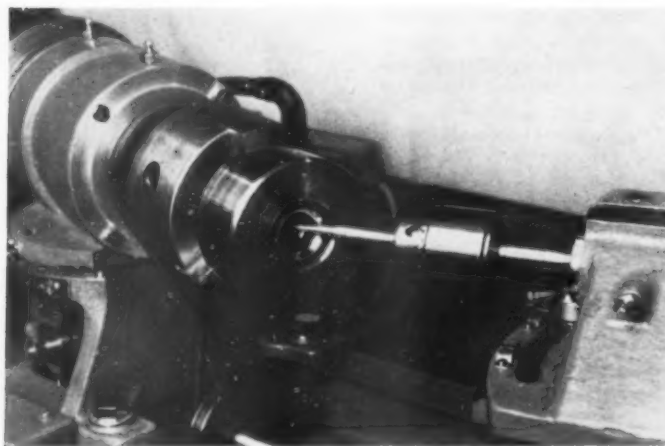
THE problem of protecting small and medium-sized products from corrosion, during storage and transport, has been simplified by the development of plastic coatings which form a sheath round the part and which may be peeled off when the part is required for use. Messrs. Croda, Ltd. have marketed two compositions for this purpose, Crocell, applied by hot-dipping and Lowerite, applied by cold-dipping, brushing or spraying.

Crocell cuts clean away from all preconceived methods of rust prevention, being neither a grease, oil, wax nor varnish. Instead, a tough, thick thermoplastic skin is formed over parts to be protected by dipping them into Crocell. This skin is not only impervious to all forms of corrosion but, due to its plastic nature, combines this with considerable cushioning properties, which protect the contents from knocks and abrasions during storage and transport and, at the same time, reduces the cost and bulk of normal packing materials. The Crocell skin is easily removed by slitting open, when it comes away in one piece leaving a film of purest lubricating oil, which is exuded by the film during storage.

Compared with existing types of rust preventives, Crocell is not cheap, but for expensive precision work the high degree of protection it provides and the extraordinarily large amount of packing which it saves easily nullify the initial cost. Crocell is specially recommended for machine tools, gauges, machined surfaces, lathe chucks, drills, gears, connecting rods, valves, bearings, etc.

Articles to be protected must be immersed for 15/20 seconds in a bath of Crocell maintained at a temperature of 190°/200° C. The thickness of the coating can be varied within this temperature range, the average being about 0.085 in. Thinner coatings can be applied by first heating the parts to a temperature in the same region as the molten Crocell. The Crocell solidifies within a few seconds of removal from the dipping pot and the parts can then be set aside to cool. It will be appreciated that special heating pots are required to maintain the Crocell in the correct molten condition and without local hot spots. A simple fume-extractor hood is desirable over the dip pot, and a draught-free site should be selected in order to avoid surface cooling and skinning.

The enveloping skin of Crocell is quickly removed by slitting open, preferably with a sharpened piece of wood or similar substance, which will not scratch the protected part. An alternative, is to leave *in situ* the



Close-up view of a die piercing and polishing machine finishing the entrance radius of a drawing die. Smooth reciprocating motion of the headstock produces accurate radii, or the headstock may be swung clear of the needle spindle and used as a manual polishing head.

suspension string used in dipping, which acts as a rip-cord when pulled, cutting through the plastic coating. The Crocell skin after removal can be melted and used again.

Lowerite is a plastic type anti-corrosive having similar basic properties to Crocell, but with the essential difference that it is applied cold. It is formulated on a solution of the Crocell film-forming materials in specially-balanced solvent, which gives a viscous compound suitable for application by dipping. By the addition of a special solvent blend, Lowerite can be reduced to a consistency suitable for brushing or spraying.

The plastic skin formed by Lowerite provides high resistance to corrosion and combines this with reasonable cushioning properties. Laboratory investigations aimed largely at equalling U.S.A. Government Department Specifications, show that the film applied by a single dip will resist:—(1) Exposure to 240 hours humidity at 42°–48° and 100% humidity. (2) Immersion for 10 × 3 hours in 5% salt solution at room temperatures.

The coating formed is a transparent, tough, elastic, resilient continuous membrane which can be stripped off in one piece, unless the protected part is of very complex shape. Like Crocell, the Lowerite film exudes oil on to metal surfaces, providing additional anti-corrosive properties and aiding stripping. The outer film is not oily to the touch, however. In its standard form, Lowerite provides an almost water-white transparent film. It can be supplied in a coloured form in such colours as red, green, and blue which, apart from ensuring complete coverage, gives an extremely attractive finish. Identification marks on tools, gears, etc., can easily be read through the Lowerite film, whether plain or coloured.

Articles to be protected are simply dipped into the Lowerite, one immersion giving a film thickness of approximately 0.004–5 in. The film reacts in a similar manner to Crocell, protruding sections acting as supports and resulting in a slightly thicker coating. Gaps of around  $\frac{1}{4}$  in. are easily bridged with Lowerite. If, during dipping, any "blind spots" are noticed due to bubble formation, it will be found that a quick fresh dip will usually eliminate the trouble.

The film will be found to be dry enough for handling in 1 hour and stripping is feasible in 2 hours, or anytime afterwards, by means similar to those used for Crocell. Lowerite is inflammable and needs precautions against fire, similar to those for cellulose lacquers. Its flash-point is 71° F. (S.G. 0.896).

Messrs. Croda, Ltd., Croda House, Snaith, Goole, Yorks.

### Rolling Mill Transmission Unit

AN example of the type of transmission used in modern steel rolling mills is that recently installed in Joseph Sankey and Sons' Manor Sheet Iron Works, Wolverhampton, driving a finishing and two breaking down mills on the same train. It provides a further contribution to the efficiency accruing from the mechanisation of hot steel mills under the iron and steel reorganisation programme.

This unit, manufactured by David Browns at their Huddersfield Works, comprises a

40 in. × 70 in. centres double reduction helical gear unit for a duty of 750 h.p. normal, 5,000 frequent peak and 8,000 h.p. maximum emergency peak at 720/30 r.p.m., with flywheels on the high-speed shaft having a total stored energy of 15,000 h.p. seconds. A barring gear, through a Radicon worm-reducer at 30 h.p. 1450/149 r.p.m., gives a barring speed of 0.75 r.p.m.

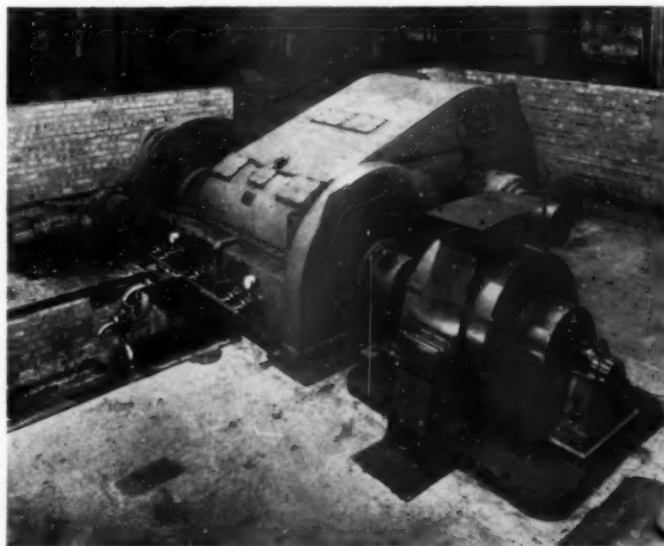
As will be seen from the illustration of the drive *in situ*, the entire installation has an unusually compact and clean-lined appearance, the skilful use of welding technique in base and cover facilitating functional and exterior maintenance. The first reduction gears have a face width of 26 in., the wheel made from chromium-molybdenum cast steel and the pinion from 2½% nickel-chrome-molybdenum forged steel. The second reduction gears, of 36 in. working face width, comprises a wheel made from 0.4% cast carbon steel and a pinion cut from 0.5/0.6% forged carbon steel. The teeth were generated by profile ground cutters to give the accuracy of pitch and tooth profile necessary to ensure shockless engagement and smooth running.

The final wheel is mounted on a substantial shaft with extensions on each side of the gear case. Each high-speed shaft extension, on either side of the case, carries a cast-steel flywheel having a kinetic energy of 7,500 h.p. seconds at 720 r.p.m., the flywheels being 80 in. diameter and 8 in. face.

Bearings consist of cast-iron shells lined with white metal, the lower halves carried in seatings integral with the bottom half of the case, and are arranged not only for ring-oiling but with a positive feed from the forced lubrication system. Bearing caps are in cast steel.

The barring gear comprises an 8 in. R.H.U. Radicon worm reducer transmitting 30 h.p. from 1,450–149 r.p.m., the low speed shaft extended to carry a single helical pinion. Barring speed is 0.75 r.p.m. The pinion of the barring gear is arranged so that the thrust from the flywheel will disengage the pinion when the flywheel over-runs.

A 40 × 70 in. centres double reduction helical gear unit for breaking down and finishing mills at Joseph Sankey and Sons' Manor Sheet Iron Works.





# MICROANALYSIS

CHEMICAL AND PHYSICAL METHODS

APPARATUS METALLURGICAL APPLICATIONS TECHNIQUE

**W**E have been reading with much pleasure and profit the first Annual Review of Analytical Chemistry, which has appeared in the January issue of "Analytical Chemistry." This review, which occupies about 170 pages, concerns itself with fundamental analysis, and together with a similar review on applied analysis, to appear in the next issue, will form an outstanding source of reference to the literature of analytical chemistry over the past five years. Here we have a milestone in the history of analytical chemistry, the recognition that its development is now so extensive as to call imperatively for an annual review of the whole field. The present review comprises 29 articles, ranging from various types of spectroscopy and other methods of instrumental analysis to inorganic and organic gravimetric and volumetric analysis. Eleven articles will fall into the applied section, and the two will subsequently be issued independently as a single-volume reprint. Incidentally, we are rather pleased by the attention accorded to "Metallurgia." Looking at the 430 references in the article on Inorganic Microchemistry, which records contributions from 112 journals, we find that, as one would expect, "Analytical Chemistry" and its predecessor, the "Analytical Edition," take pride of place with 154 references. Mikrochemie follows with 37 references, while "Metallurgia" is in the third place with 27, 15 ahead of the next in order. Since the journal is also referred to frequently in other appropriate articles in the series of reviews, we feel that the contribution of the Microanalysis Section, consisting as it does of only four pages monthly, is of a satisfactory importance in the literature of this branch of analytical chemistry.

## The Sub-Micro Balance and its Applications

### I—The Sub-Micro Balance

By G. Ingram

*Since the discovery of the transuranium elements, the development of submicro-technique has reached a stage comparable with that reached nearly forty years ago, when Pregl and others introduced quantitative methods of organic microanalysis. The success of these submicro-gravimetric methods may be attributed to the type of balance now available which is capable of determining differences of less than a microgram with a precision hitherto thought impractical for routine use. The development of such a balance is here described. A discussion of some of the possible applications of submicro-technique will be dealt with in a later article.*

#### Introduction

**U**NTIL the development nearly forty years ago of the conventional micro-balance, micro-methods of analysis were restricted to the qualitative field and to the simpler quantitative inorganic estimations. These simple micro-determinations, which involved weighing small amounts of precipitates generally of the order of 0.2–2 mgm., were possible by the use of a delicate balance designed by Nernst.<sup>1</sup> This was later modified by Donau and Emich<sup>2</sup> to carry a load of about 15 mgm. only, so that a sensitivity of less than one gamma could be obtained. The field which embraces the

chemical study on such a minute scale of operation has been given the name of sub-microchemistry. Because of the advantages associated with carrying out the usual large-scale processes on a small amount of material, and owing to the fact that developments in the field of research are in the main creating a need for these specialised methods, the importance attached to their development may well be compared with that shown during the development of ordinary micro-chemical technique. A typical example of this need is the recent discovery and isolation of the transuranium elements, which has established a highly-specialised form of procedure of far-reaching importance in the field of analytical chemistry. The results achieved have shown great

<sup>1</sup> Nernst and Riessfeld, *Ber. dtsch. Chem. Ges.*, 1903, **36**, 2,086.

<sup>2</sup> Donau and Emich, *Monatsh.*, 1915, **36**, 412; *Abderhalden*, 1919, 102.



possibilities in the carrying out of the usual micro-scale procedures on amounts approaching a thousandth part of a milligram, with an accuracy of less than 1%.

The pioneer work of Benedetti-Pichler and the earlier micro-chemists, Emich and Donau, have contributed much in providing a background of manipulative technique for submicrochemistry in both the qualitative and quantitative inorganic fields. However, until the recent investigations connected with the transuranium elements, the quantitative field has been restricted in scope because balances hitherto developed, though sufficiently sensitive, were unsuitable for routine use. They are subject to disturbance by temperature changes, radiation and vibration. A balance which is practically unaffected by these disturbances, and is more robust and simple in operation has been constructed by Kirk<sup>3</sup> and others, connected with developments in atomic

need. These balances were of a delicate nature, since in order to carry out quantitative determinations on samples of a few micrograms in mass, a precision of weighing of at least 0.01  $\mu\text{g.}$  was required. Sensitivities of this order are readily obtained when the maximum load is reduced to a relative figure, but sufficiently large enough to allow manipulation of the object or sample to be weighed.

In order to attain this precision, quartz has been used almost universally in the construction of the balances. This was necessary because metals are too readily affected by temperature changes and other well-known disturbances.

Warburg and Ihmori<sup>4</sup> in 1886 were probably the first to construct a simple balance capable of weighing well below the limits attainable with balances then available. From then onwards numerous designs

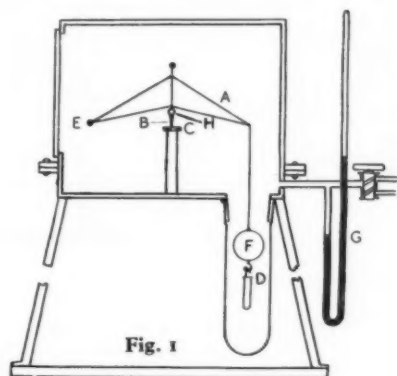


Fig. 1

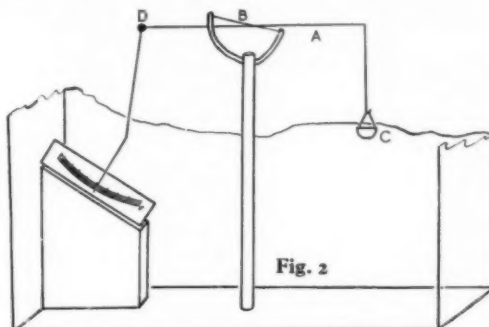


Fig. 2

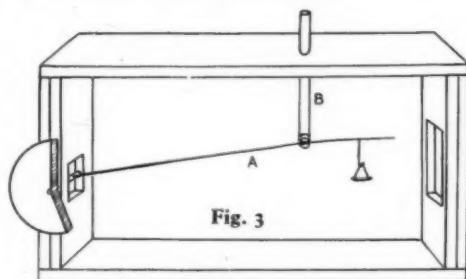


Fig. 3

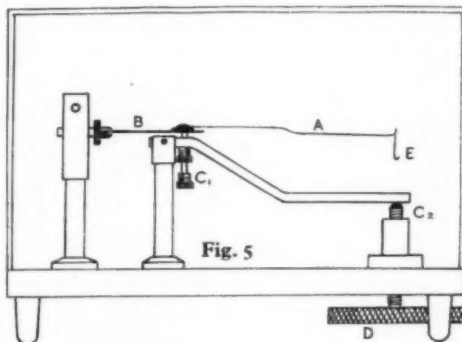


Fig. 4



Fig. 5

Fig. 1.—Early quartz fibre balance by Steele and Grant.

Fig. 2.—Nernst balance.

Fig. 3.—Simple Salvioni balance.

Fig. 4.—Emich spring balance.

Fig. 5.—Lord strip-beam balance.

research. Its design is such that weight differences as small as 0.005  $\mu\text{g.}$  are detectable, it is capable of weighing loads up to 300  $\mu\text{g.}$ , and the beam can support a weight of 0.2 gr. without any appreciable decrease in the sensitivity of the balance. In fact, as its possible uses far exceed the purpose for which it was intended, it may well prove to become the balance of the submicro-chemist.

#### Development of Submicrobalances

The aim of the pioneer microchemists was to develop methods of analysis using microgram amounts of material. For this work they constructed refined balances, generally, suitable for their own particular

covering a wide range in sensitivity have been described. Emich<sup>5</sup> and later Gorbach<sup>6</sup> have published comprehensive reviews of these balances.

The use of quartz in their construction meant, in some cases, that a design of a simple nature could be followed. An early model such as that illustrated in Fig. 1 consists of a quartz beam A, with a central bearing B, a quartz knife-edge resting on a polished quartz plane C. The balance pan D is supported by a hook which is suspended from a length of fine quartz fibre sealed to one end of the beam and counterpoised at its other with a blob of quartz E. It is operated inside an air-tight

<sup>4</sup> Warburg and Ihmori, *Ann. Physik u. Chem.*, N.F., 1886, **27**, 481, 1887, **31**, 145.

<sup>5</sup> Emich, *Abderhalden*, 1919, **9**, 55.

<sup>6</sup> Gorbach, *Mikrochemie*, 1936, **20**, 254.

<sup>3</sup> Kirk, Craig, Gullberg, and Boyer, *Anal. Chem.*, 1947, **19**, 427.

case as the relative mass is obtained by measuring the change of buoyant effect required to return the beam to its original point of rest. This effect is accomplished by altering the pressure inside the balance case and so changing the buoyancy of a quartz bulb F attached to the suspension of the pan. The pressure difference is shown by the manometer G and oscillations are observed by a beam of light reflected from a small mirror H, fixed to the centre of the quartz beam, on to a scale situated outside the balance case.

The sensitivity of this type of balance is extremely small as was shown by the originators, Steele and Grant,<sup>7</sup> and later by Gray and Ramsay<sup>8</sup> who were able to measure differences of mass to within 1/500,000 mgm. The need for careful control of pressure during weighing and the additional manipulative technique involved, does unfortunately retard its use in normal analytical work. Nevertheless its general design has contributed much towards the modern conception of sub-micro-balances.

A simpler balance (Fig. 2) was constructed by Nernst<sup>1</sup> and improved by Emich and Donau<sup>2</sup> for use in general inorganic analysis. The beam is a quartz fibre A fused to a finer thread B at its central point, the finer thread being held between upright supports. The sample is placed on the pan C and its weight determined by measuring the amount of torsion put on the quartz thread. The pan is suspended from one end of the beam by means of a fine quartz thread terminating in a hook. The other end of the beam carries a quartz counterpoise D to which is fused a long thin fibre bent downwards and ending in a fine point. A calibrated scale is situated behind the tip of the pointer so that its displacement can be accurately read by means of a telescopic lens. With this type of balance weights accurate to about 3  $\mu$ g. for a maximum load of about 0.5 gm. have been obtained. With a more refined model lower limits of 0.8  $\mu$ g. have been obtained with a load of 15 mgm.

In an even simpler type of balance developed by Salvioni,<sup>9</sup> the determination of the weight depends upon the measurement of the amount of bending of a single fibre. The balance is shown in Fig. 3. The beam A is fastened at one end to a solid base which can be rotated. The pan is suspended near the free end allowing the projected portion to be used as a pointer. The displacement of this, caused by the addition of a weight on the pan, is read by means of a reading microscope, accurate to about 0.002 mm. To assist loading, the balance is provided with an adjustable stop B, which projects through the top of the balance case. The balance has a maximum load of 0.5 mgm. and a weighing range of 20  $\mu$ g. sensitive to within 0.02  $\mu$ g.

Although generally quartz has been used in the construction of delicate balances, other users have been successful employing material such as phosphor-bronze for the beam, whilst others have used the coil principle in place of the cantilever beam.

The Hartmann and Braun<sup>10</sup> spring balance is useful in cases where rapid weighings are required. For this reason this type has found useful application, not only in the field of microchemistry but in certain industries where small objects have continually to be weighed. Therefore, these balances can be obtained with maximum

loads varying over a wide range. The earlier model was used by Bang<sup>11</sup> for his classical work on blood analysis whereby he used only a drop of blood sample. This had a maximum load of 6 mgm. and was readable to 0.005 mgm. The object to be weighed is simply hung on the hook of the balance, and by rotating an arm fixed to a pointer until zero is reached, the weight is read off on a clock-face dial graduated in  $\frac{1}{10}$  mgm.

Another type of spring balance is that due to Emich<sup>12</sup> shown in Fig. 4. It consists of a finely-wound quartz coil spring A suspended from the top of a glass-tubular

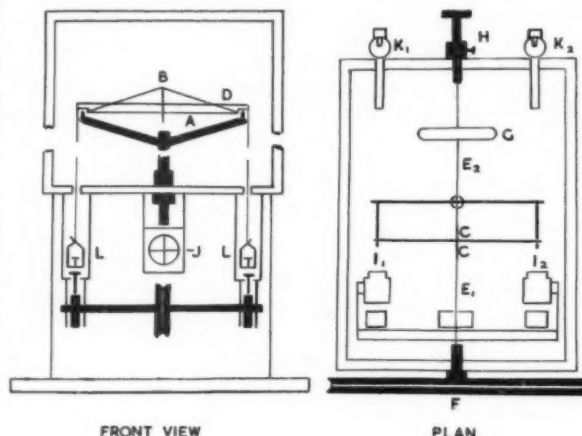


Fig. 6.—Modern quartz microgram balance.

cover by means of the sliding rod B. The free end supports a platinum holder C and a pointer D underneath which is a hook for suspending a small pan or other objects to be weighed. The additional weight causes the spring to expand with a corresponding shift in the height of the pointer. This difference is measured by projecting the image of D, together with a scale, on to a lantern screen. Calibration is carried out with 5 and 10 mgm. riders.

As this type of balance is suitable for loads of between 10 and 30 mgm. in weight, it is particularly suited to study the absorption rate between solids and gases. The construction of it allows it to be incorporated into an evacuated system and if need be, conveniently thermostated.

A recent advancement by Lord<sup>13</sup> for determining the weight of a single centimeter length of cotton utilises the deflection principle, using a strip of fine phosphor-bronze ribbon as the beam. The ribbon A (Fig. 5), is mounted horizontally and secured at one end with sealing wax to a flat steel spring B. The beam is provided with a zero adjustment device C 1 and C 2, controlled from outside the balance case by means of the screw D. The specimen to be weighed is placed on the hook E which is formed by bending the free end. The displacement of the beam at its extreme end is measured by means of a pocket microscope containing a scale in the eyepiece. One having a nominal magnification of 10 $\times$ –30 $\times$  is suitable.

By resorting to beams of different thicknesses, length and breadth, varying sensitivities can be achieved.

<sup>7</sup> Steele and Grant, *Proc. Roy. Soc. Ser. A*, 1909, **82**, 580.

<sup>8</sup> Gray and Ramsay, *Compt. rend.*, 1910, **151**, 126.

<sup>9</sup> Salvioni, *Metall.*, 1901.

<sup>10</sup> Hartmann and Braun (Balance described by Voller, *Z. Angew. Chem.*, 1915, **28**, 54).

<sup>11</sup> Bang, *Biochem. Z.*, 1918, **87**, 248.

<sup>12</sup> Emich, *Monatsh.*, 1915, **36**, 456.

<sup>13</sup> Lord, *Shirley Institute Memoirs*, 1947, **21**, 1.

Thus with a beam 89 mm. in length, 0.501 mm. in breadth, and 0.098 mm. thick, a total load of 9 mgm. for a full-scale deflection was obtained. With one having the dimensions of  $89.5 \times 0.141 \times 0.0319$  mm. a full-scale deflection equivalent to 0.106 mgm. was obtained. Even lower sensitivities having a full-scale deflection equivalent 0.0266 mgm. were obtained when the dimensions were reduced further. Calibration of the balance is carried out by means of standard weights.

Pettersson<sup>14</sup> and later Neher<sup>15</sup> have constructed balances which include improvement of outstanding usefulness. These together with other new features have been used in the construction of the quartz microgram-balance.

### The Quartz Microgram Balance

An unusual feature of this balance is the use of the conventional system of beam and pan arrests. The balance, shown diagrammatically in Fig. 6 comprises the torsion principle of Neher, the pan suspension of Steele and Grant, the pan well of Pettersson, and a comparison microscope for evaluating the beam position.

The beam is of rigid construction so that the main load, the pans and their suspensions, are balanced by gravity.

Measurement of the torsion applied to the fibre when an additional load is placed on one of the pans is accomplished by rotation of a large graduated wheel until the beam is restored to the horizontal. The scale is readable to one minute of arc with a vernier. The return of the beam to its normal position is observed by means of a simple optical system.

The entire quartz assembly is made up on a set of quartz jigs which allow their accurate reproduction and a great reduction in construction time. Details of this jig may be the subject of a further publication.

The triangular form beam is 10 cm. long and 1 cm. high at its central point, and is constructed from quartz fibres of various diameters. A, B, and C are approximately 200  $\mu$ , the brace 60-75  $\mu$ , and the horizontal index fibre D 15  $\mu$  in diameter. The protruding lower portion of the vertical fibre B is required for adjusting the centre of gravity.

The torsion member consists of a cross-piece fused to the main beam fibre to which the torsion fibres E 1, E 2 are also fused. The diameter of the torsion fibres are approximately 20  $\mu$  and are 5 cm. in length. The front one E 1 is fused to a rigid quartz stem which is cemented into the rotating axis of the calibrated wheel F. The rear torsion member is fused to a quartz bow G which is in turn fixed to an adjusting mechanism H by which the tension of the bow, and therefore of the torsion fibre is changed.

The pan suspension fibres are about 5  $\mu$  in diameter and terminate in a small hook from which the pan stirrups are hung.

The beam is supported inside the case in a conventional manner with a beam arrest, lowered from outside the case from a distance by means of a pulley cord. The pan arrests are also controlled by this means, using a cam mechanism for raising or lowering them.

The graduated wheel is rotated by an endless cord and system of pulleys to provide smooth control without back-lash, and the vernier scale is illuminated by an outside spot light. Although no mention is made in the

original paper, it is probable that as the balance is operated by remote control, the vernier scale is read with a telescope.

The pan wells L situated below the balance, house the pan stirrups. The fine quartz fibres for suspending them pass through small holes in the floor of the case. The pans, which rest on small platforms of quartz fibre, sealed to the stirrups, are cut from very thin platinum foil, each one weighing about 20 mgm. and 6 mm. in diameter. Semi-circular rotating doors are fixed to the pan wells to enable the sample to be placed on the pan.

The optical system is situated inside the balance case fitted to a removable plate. It consists of comparison microscopes I 1 and I 2 which are focussed with objections of  $3 \times$  magnification on corresponding parts of opposite ends of the fibre D. The path of the projection is controlled by means of  $90^\circ$  prisms so that it emerges below the balance case towards the operator. The parallel beams are brought into apposition in a biprism and the double image projected through a 6X triplet magnifier on to a ground-glass screen J. The indication fibre D is illuminated by light from two flashlight bulbs K 1 and K 2 situated outside the balance case. The light is led through the wall of the case by lucite (*Perspex*) rods.

To prevent dust and air currents from disturbing the quartz mechanism, it is surrounded by a brass case and a further one of insulating board over it to minimise the effect of temperature change.

The balance is extremely simple and rapid to operate. After allowing it to reach equilibrium, the pan releases are operated and the large wheel adjusted until the beam is in a horizontal position. The pan is then removed from the pan well, through its semi-circular rotating door, loaded with the sample and replaced. The wheel is then again rotated until the fibre image formed on the ground-glass screen is in a continuous line across the field. The difference in the readings before and after loading the balance gives the weight of sample.

### Microchemistry Group

At the Fifth Annual General Meeting of the Microchemistry Group of the Society of Public Analysts and Other Analytical Chemists, held on Friday, January 28, the following new Officers and Members of Committee were elected for 1949:—

*Chairman*: Mr. Ronald Belcher.

*Vice-Chairman*: Dr. Cecil L. Wilson.

*Hon. Secretary*: Mr. Donald F. Phillips.

*Members of Committee*: Mr. A. E. Heron, Mr. C. E. Spooner, Mr. D. W. Wilson and Dr. G. H. Wyatt.

Dr. A. F. Colson and Mr. G. Ingram continue as Members of Committee, having been elected in January, 1948.

### Cantor Lectures: The Corrosion of Metals

DR. W. H. VERNON, O.B.E., of the Chemical Research Laboratory, Department of Scientific and Industrial Research, has been invited by the Royal Society of Arts to deliver two Cantor Lectures on the corrosion of metals. The first lecture, to be given on Monday, February 21, 1949, will deal with general principles, whilst the second, on the following Monday, concerns preventive measures.

<sup>14</sup> Pettersson, "New Micro-balance and its use," Stockholm, Göteborg, 1914.  
<sup>15</sup> Neher, M. Strong's "Procedures in Experimental Physics," New York, 1942.



# METALLURGICAL DIGEST

## The Noble Metals find increasingly wide use in Industry

By F. E. Carter

**M**ORE exacting demands are being made for metals and alloys capable of withstanding extreme conditions of temperature, pressure and corrosive agents. Metallurgists have responded with many excellent base metal materials, but none of these can be counted perfectly satisfactory; one may withstand corrosion but will not stand heating without oxidising or melting; another may withstand high temperature but may be attacked by corrosive agents; while another may break down under pressure.

The properties of the noble metals satisfy many of the requirements and industry is making rapid strides in introducing them as the preferred material to use in chemical equipment. Certainly the initial outlay is high, especially for large pieces of equipment, but the value as scrap is only slightly less than the market price of new metal.

The noble metals comprise the six metals of the platinum group: platinum, iridium, osmium, palladium, rhodium and ruthenium, together with gold and silver. Of these silver has by far the largest use in the chemical industry as a constructional material. Of the others those most used are platinum, palladium and gold, although the remaining four metals are highly important as alloying elements, where it is desired to have greater strength, hardness, or resistance to corrosion.

Of the many uses of the noble metals as a construction material only a few can be given here, but these applications show how important they have become in assisting to overcome many of the problems associated with industrial progress.

The glass industry has recognised the value of platinum in protecting the refractory walls of glass furnaces from the severe corrosive action of molten glass. Even the best of

refractories are perceptibly eroded by molten glass, especially when the latter is in motion; to prevent erosion, parts of the furnaces, particularly channels, pouring spouts, etc., are lined with platinum. Palladium has given excellent results as a liner for dies in the manufacture of bottle glass; thousands of tons of this low fusing glass have been fed from such lined dies without visible deterioration of the liner. One particular application of noble metals in the glass industry is in the manufacture of electric light bulbs; here a certain definite amount of molten glass is required to seal the bulb into its base. Formerly, the glass had been delivered through a refractory die which, however, enlarged so much by erosion of the flowing glass that soon an excess of glass in a unit of time was delivered, and in consequence the machine had to be stopped while a new die was inserted. A lining of platinum increased the life of the die a hundredfold.

The great industry of synthetic fibres depends on the noble metals for its spinnerets. No other material than noble metal alloys seems to have all the properties desired by this industry. Alloys of platinum-rhodium, gold-platinum, gold-palladium, etc., can be so fabricated that the numerous minute holes of the spinneret can be made extremely accurate, both as to size and shape. The holes retain their size for a long time and are easily cleaned out whenever there is any tendency to stoppage by the viscous mass.

Important amounts of the platinum metals are used in the electrochemical industry for insoluble anodes. Sheets or rods of platinum or iridium-platinum are frequently used; for very large installations it is usual to encase a base metal anode in a sheath of noble metal. The union between the base and the cladding is so complete that the resistance to even heavy currents is only insignificantly increased. The

preferable form of clad anode is a U-shape rod, since there is no danger of the base metal being exposed; straight rods or sheets are also used, but special precautions are necessary to seal completely the ends or edges. The two important advantages of noble metal anodes are long life and purity of product.

Increasing use of rupture discs is being made in the chemical industry to act as a simple form of safety valve; and when corrosive materials are being processed, it is necessary that these discs be made of noble metals. By proper selection of diameter and thickness and by close control of fabrication methods the discs can be made to "blow" at any desired point between a few pounds and thousands of pounds pressure.

The noble metals find a large use in the field of electrical contacts. Since they do not form a superficial layer of insulating oxide, they are particularly valuable for contacts which "make" with very light pressures. Iridio-platinum is used in aviation magnetos and other instruments, palladium and its alloys in telephone circuits, and indeed, wherever absolute dependability is required noble metal contacts are preferred.

Recently, there has been a sort of reversion to the original method of handling platinum, namely to the powder metallurgy process. By this process and by suitable addition agents, platinum and some of its alloys have been prepared with properties superior to those of the cast alloys; they are considerably stiffer and retain their strength at elevated temperatures much better than do cast materials. These qualities have caused them to be introduced as electrodes in aviation spark plugs, as laboratory ware, etc., and no doubt other applications will arise in the near future.

Palladium is finding increasing uses in industry in addition to the more generally known applications in the dental and electrical contact fields. One example, in addition to that already mentioned in the bottle glass industry, is its use as trays for ignition of the various special powders used in treating the glass tubes for fluorescent

From *Materials and Methods*, 1948 (Nov.), 28, 55-59.



lighting. Another is the very considerable development of gas purification, where a palladium catalyst is used to remove the last traces of oxygen from hydrogen; for many present-day processes absolutely pure hydrogen is required, and many large installations have already been made for purifying by this method. An alternative method of getting pure hydrogen is to make use of the unique diffusing property of palladium, which permits hydrogen, and hydrogen alone, to pass through.

These few examples of the use of the noble metals in industry are merely typical and could be multiplied many times, but in this place nothing more than a mere mention of several other uses can be included. There come to mind all the forms of laboratory ware, crucibles, dishes, electrodes, etc., for

which platinum is essential; noble metal thermocouples; platinum for resistance thermometers; the numerous alloys with highly specialised properties for the dental field; fuse wires of iridio-platinum for detonating caps in the explosive field; and many others. Noble metal catalysts in the synthetic nitric and sulphuric acid fields take very large quantities of these metals, and in the field of synthetic organic chemistry, platinum and palladium are widely used. Even this enumeration does not cover by far the various uses to which the noble metals are put in industry and, so broad and so important are their applications, it is difficult to imagine what we could do without them; indeed, it is interesting to speculate on the highly important station they occupy in our modern civilisation.

## Close Control required in casting High-conductivity Copper Alloys for Welding Jaws

By Paul G. Maganus

IN designing the welding jaws for spot welders, especially for portable welding guns, it was necessary to make a choice of material. Since clamping pressure had to be exerted through the jaws, a high degree of strength was called for and the electrical currents carried demanded the use of a material with excellent electrical conductivity to maintain the efficiency of the machine. Two compositions meet requirements for components of this type: cast high-conductivity copper, used when some sacrifice of strength can be made in the interest of the best possible conductivity, and cast beryllium-nickel-copper alloy, used when strength must be combined with high conductivity.

Production of the pieces required in these copper-base compositions entail foundry techniques differing somewhat from those in the ordinary brass foundry, with controls carried to a greater degree. Slight changes in the treatment of the melt will lower the electrical conductivity of the conductive copper from an equivalent of 90% to about 80%. This change is very important in a material designed for maximum conductivity.

Control of the quality of the ingot materials is of utmost importance. No scrap metal whatever is used in making up the charges; copper is supplied as electrolytic copper, and the alloying elements as master alloys of high purity. Gates and risers normally compose not more than 50% of the melt so as to obtain metal of the dense quality required, and are carefully segregated according to composition, cleaned, and returned to the appropriate storage space.

A complicating factor in producing the copper and alloy castings for welding applications is that most of them must have cast-in tubes for cooling water. These tubes are of nickel, stainless steel, or plain carbon steel, depending upon conditions in the end use of the product. It is necessary, then, to pour the copper around the tube in the mould so as to (1) insure a good bond between tube and copper over all mutual areas, to obtain rapid heat transfer in the finished piece; and (2) to prevent collapse of the tube during the period when it is subjected to the heat of the molten copper, or while the metal cools and contracts.

The problem of tube collapse has been met by closing both ends of the tube and filling with nitrogen gas at a

pressure just above atmospheric before sealing. This not only prevents collapse of the tube, but stops any molten metal penetration of the tube through a defective seam, and reduces the danger of "blows" in the casting. Shot blasting of the external surfaces of the tube has been sufficient to effect a good bond during casting in most cases, but coating of the tube with copper, by either electroplating or metallising, has been resorted to when necessary.

Beryllium-nickel-copper alloy castings have the following composition:

|                     |         |
|---------------------|---------|
| Beryllium . . . . . | 0.5%    |
| Nickel . . . . .    | 2.0%    |
| Copper . . . . .    | Balance |

In making up the charge for the furnaces, nickel shot is preheated with dry charcoal in the pots, and electrolytic copper is then added. The nickel shot is 93% nickel, and about 6% silicon. With the flame held at or near the neutral point, the material is melted down at 1,230° C. The silicon acts as a deoxidizer, but to be sure of deoxidization before adding the beryllium the melt is deoxidized with lithium-copper, using a little more than 1% of the weight of the melt. The lithium-copper is about 2% lithium, and is added by introducing to the bottom of the pot, and stirring. The melt is then purged with dry nitrogen gas for about 3 minutes. A stainless steel tube with  $\frac{1}{4}$  in. holes along its sides, and with the end sealed off, carries the nitrogen gas to the bottom of the pot and permits it to bubble through the melt.

Beryllium is added as a 4% master alloy with copper. The ingots of the concentrate are preheated to about 540° C. before addition to the furnace; this cools the melt to about 1,100° C. It is reheated to pouring temperature, about 1,180° C., and poured immediately. Super-heating and long holding favour burning away of the beryllium, and contamination with the furnace gases. An exothermic riser compound is used immediately after pouring the metal to provide a hot top in the open risers. The castings are then permitted to cool to about 540° C for shakeout.

After a careful cleaning, the castings are given a solution heat treatment at 840° C. for 2 hours or more, depending upon the size of the casting. A cold-water directional quench follows, and a precipitation treatment completes the process. Precipitation is carried out at 465°-480° C. for about 3 to 4 hours, the time and temperature depending upon various conditions.

From *Materials and Methods*, 1948, November, 28, 69-71.

The copper-alloy castings made by this procedure will have the following properties:

Electrical conductivity 55% of standard copper.

Tensile strength 32-34 tons/sq. in. average.

Yield strength (1/100 in. in 2 in.)

20-22 tons/sq. in.

Elongation .. 10-13%.

Density .. 0.32 lb. per cu. in.

Hardness .. 85-90 Rockwell B

When the design requirements are such that electrical conductivity must be higher than is possible to obtain with the strong alloy, the parts may be cast of high-conductivity copper. In this case the charge consists of electrolytic copper only, with about 2 oz. of phosphorus added to deoxidize the melt. The phosphorus is about 15% phosphorus. After melt-down, lithium-copper is added, as in the case of the beryllium alloy, and a purge with nitrogen follows.

Pouring is done as with the alloy, and the copper comes out of the moulds dead soft, due to the complete annealing in the moulds. Physical properties are about as follows:

Tensile strength 11.5 tons/sq. in.

Elongation .. 50%.

Hardness .. 30 Brinell (500 kg. load, 10 mm. ball).

Electrical

conductivity 80-90% of standard copper.

While electrical conductivity will fall within the 80-90% range, it is controllable within that range to some extent. If a conductivity of about 90% is required, deoxidization with phosphorus is omitted and especial care is taken to avoid contamination of the metal.

If the design requirements dictate the use of high-conductivity copper, but the member must still carry stresses, the piece is made larger than a similar member of beryllium-copper alloy.

Proper cooling of the mould is essential and its importance increases as the casting rate is raised. The more rapid the casting rate, the greater the quantity of heat which must be absorbed by the surface of the mould.

It was found that a number of metals performed almost equally well as a mould material. The Babcock & Wilcox Tube Company has used  $\frac{1}{8}$ -in. steel,  $\frac{1}{4}$ -in. copper, and  $\frac{3}{16}$ -in. brass. It has been found that brass has definite structural and fabrication advantages.

Since continuous casting requires a slag-free steel, the steel is poured from the holding furnace into a tundish, designed to strain out the slag. From the tundish the steel flows into the mould. A preheated tundish has been used, but a specially designed electrically-heated one will be installed.

Below the mould the casting passes through an insulated chamber which arrests and controls the speed of further cooling.

Below this chamber is the withdrawal mechanism regulating the speed of movement of the steel billet. The casting then passes an oxyacetylene torch which travels down the billet a short distance while the billet is being cut to specified length which can be as much as 35 ft. The cut-off section of billet is lowered to a horizontal position by a cradle arrangement.

Results have indicated that ovals of special proportions are the most practicable cross sections to cast continuously. These ovals will readily go into a rolling mill for shaping into rounds, or can be rolled into flats.

Continuous casting meets fully-established criteria of sound steel-making practice and is said to have certain advantages over the conventional method. It allows faster cooling, which results in a fine and uniform crystalline structure with very little segregation. It offers less opportunity for dirt or other foreign material to enter the castings and, in general, the surface of the ingot will be freer of checking and scabs, and its interior free of entrapped slag.

Flexibility of the heat-withdrawal pattern means that it is easier to solidify the steel in the mould progressively from the bottom to the top. Although the mould is of uniform cross section, it approximates in behaviour the big-end-up mould—the type used for the best-quality steels.

Ingot casting by this method are cooled quickly and therefore tend toward a fine grain rather than columnar crystal structure. The billets may be as long as desired and have no taper.

## Continuous Steel Casting

### From Liquid Phase to Semi-finished Shape

A MACHINE that will make steel from the liquid phase to the semi-finished shape is reported to have been jointly developed by the Republic Steel Corporation and The Babcock & Wilcox Tube Company.

The results, demonstrated in continuous casting of semi-finished steel, were said in the announcement to open up important possibilities to the entire steel industry through increasing productivity and decentralizing production by simplification of apparatus and increasing the final yield of steel from the original melt. The new method and apparatus are considered a timely response to great economic pressure to serve areas locally.

The greatest single advantage of this process, according to the announcement, is that it removes from the conventional process of steelmaking the most massive and expensive parts of plants, such as equipment for ingots, soaking pits, and the blooming mill. Instead, continuous casting permits passing directly from the melt to semi-finished sections ready for secondary mills with the result that not only is the capital cost for a given output greatly reduced, but also maintenance and operational costs. The work accomplished to date makes it clear that for the production of relatively small

quantities of steel, and particularly as a means of decentralizing steel production, this new development fills the requirements of low capital and low operational costs.

The unit casts two or three times per week, handling both carbon and alloy steels. A section of about 30 sq. in. has been used in this work and is satisfactory for commercial use at a rate of 400 lb. per min. It is expected that continued work on this section will add considerably to the rate. A mould for a cross section of about 45 sq. in. is now under construction.

This unit is located at the top of a 75-ft. tower to which steel is delivered from the company's regular electric furnaces, and is lifted to the top of the tower in a transfer ladle. There it is poured into an inductively heated holding and pouring ladle.

By watching the liquid steel in the mould by a mirror arrangement, the operators can see at all times whether the liquid surface is clean and the process functioning properly.

Shortly after the shell of the billet has been formed the steel contracts, and in so doing the billet shrinks away from the mould. The metal, therefore, is in contact with the surface of the mould for only a few inches, and only in this short distance can it lose heat to the mould by direct contact.

From *Mechanical Engineering*, Oct., 1948.



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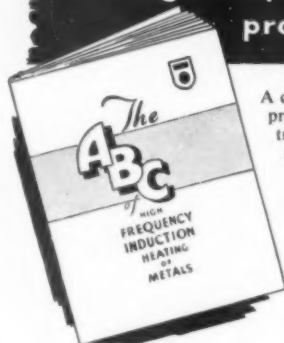
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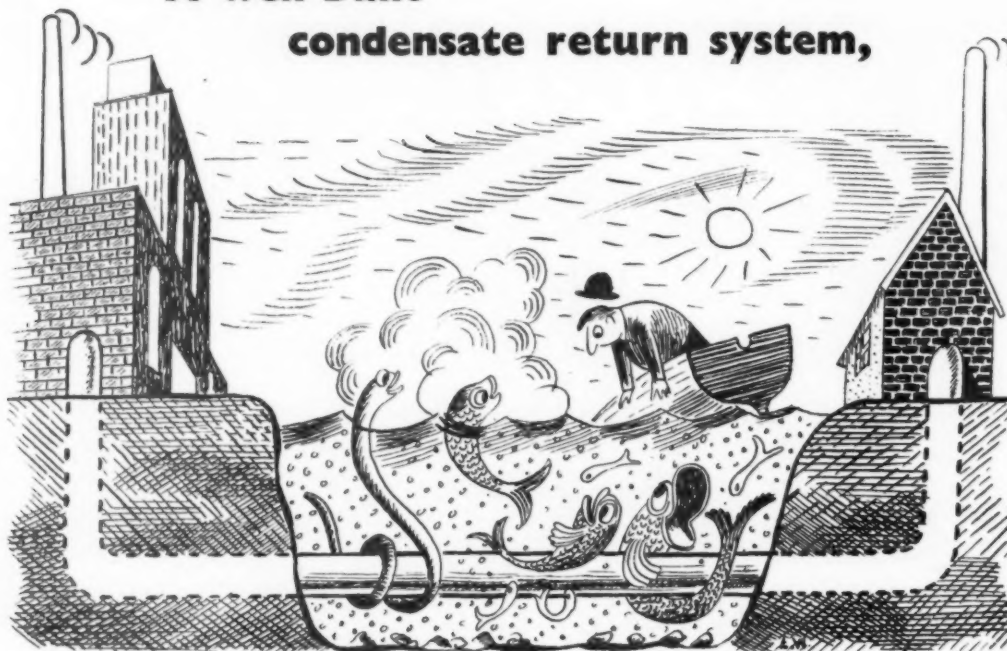
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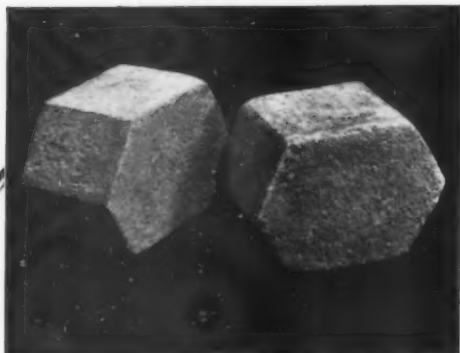
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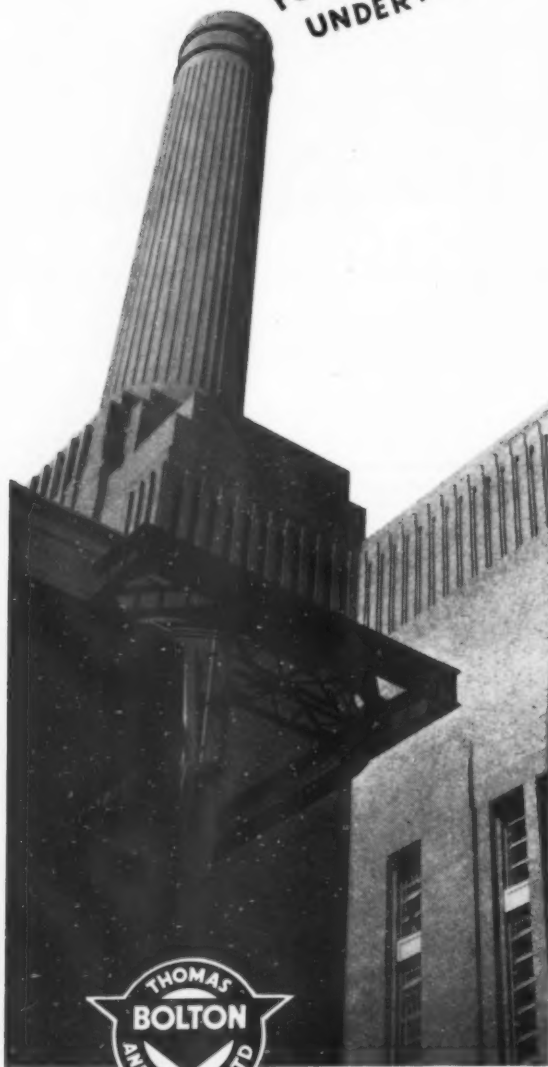
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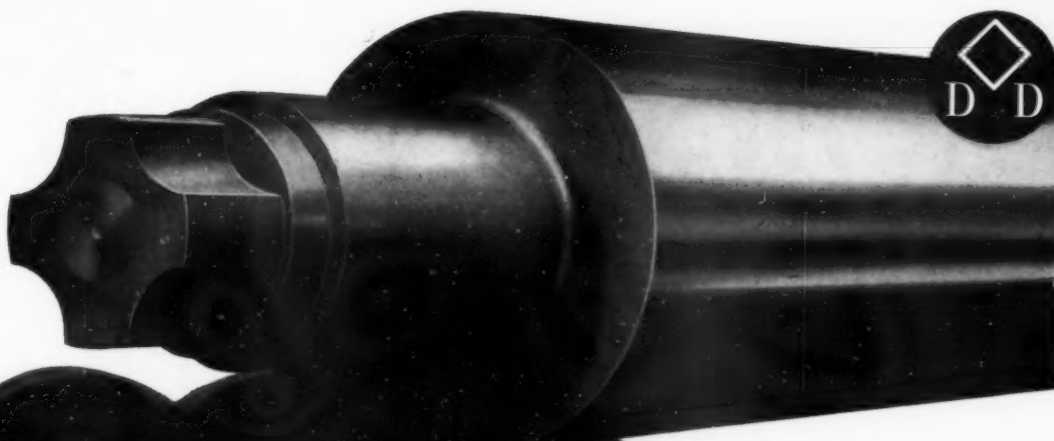
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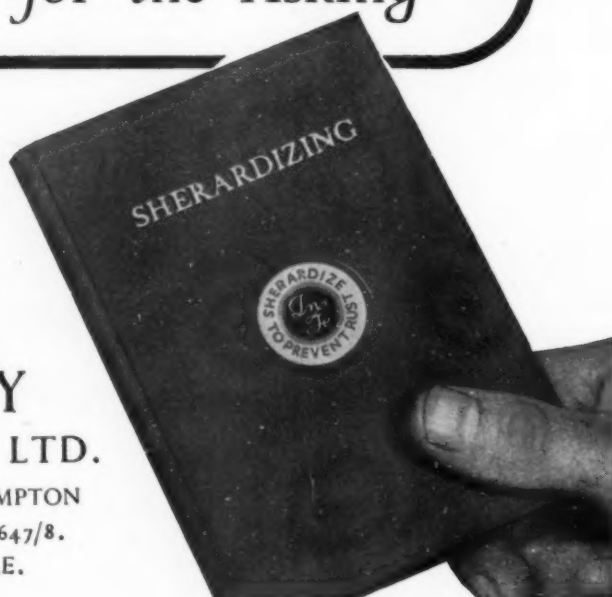
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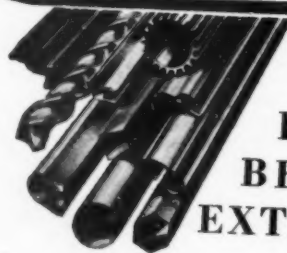
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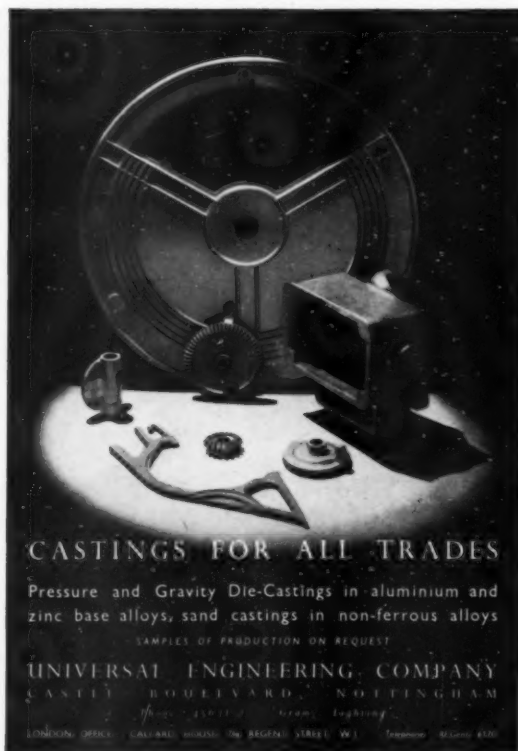
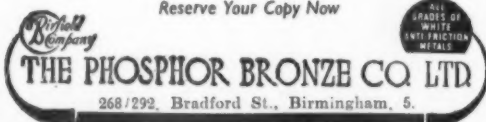
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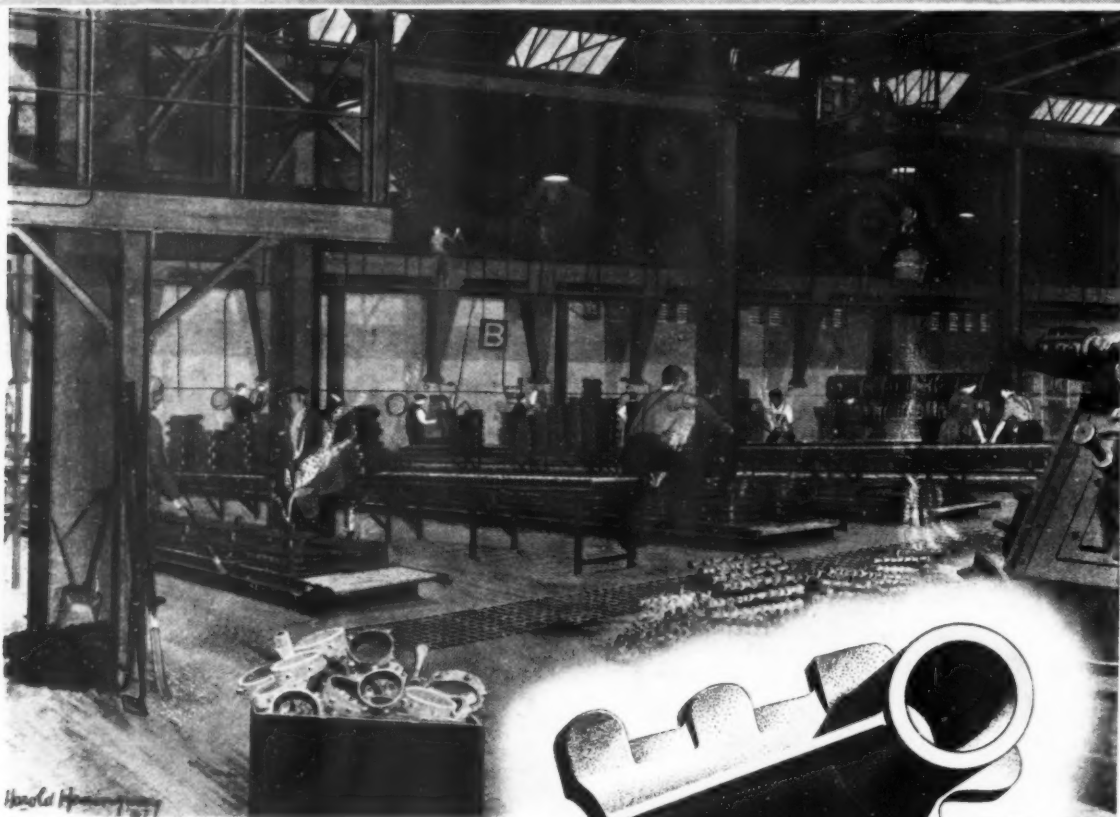
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